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Inbound Supply Risk Identification

Case OEM Telecom Supplier

Pro gradu -tutkielma
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ABSTRACT

In the modern business environment, companies are aligned in lean and complex networks, supplying products to global customers. In order to remain competitive in costs, capabilities, and innovation, companies have to focus on their core competences. Companies engaged in value adding activities are increasingly dependent on their upstream suppliers. As network structures are becoming more complex, uncertainties and risk exposures with suppliers are high. Uncertainties in supply are compounded with uncertainties in demand: customers expect better performing products and services at shorter lead times. Uncertainties in supply are entangled in a dynamic web of inherent risks that companies have to manage in order to survive.

This thesis attempts to identify and classify the most relevant sources of operative supply risks, emphasizing industry specific factors and the hub operating model of the case company, which is a global OEM equipment supplier in telecommunications. A supply risk is defined as the supply failure from an external supplier, resulting in the inability to fulfil customer demand. The direct effects are increasing customer dissatisfaction, the creation of delivery backlogs – or in the worst case losing sales or even the customer account. These impacts can be crucial to the success of the company. The supply risks are classified as related to 1) suppliers, 2) risks faced by 1-tier suppliers, 3) products, and 4) the macro-environment. All of the four risk factors are incorporated in a framework that assesses supply risk at product level.

Risks have been found to have inherent dependencies and correlations, and some risks tend to be propagated in propensity or level of affinity by other risks. This thesis proposes preliminary results of correlations between some of the identified risk sources in a risk correlations matrix. These findings can be used in order to gain knowledge on potentially escalating risk tendencies: the most dependent product risks are the excess purchase risk and the procurement lead time. The factors with the most impact on other risks are changes in demand requirements, technical complexity, and substitutability of the product. Correspondingly, the most impacting factors of supplier risks are the supplier's financial stability, the level of alignment with the OEM, and sub-supplier risks.

The thesis outlines the complete process for supply risk management. It includes risk identification to achieve a valid basis for risk assessment; classification to gain a structured approach; assessment and prioritization to allocate risk management resources; management, which is divided to proactive and reactive approaches. The identification defines the supply risk event, its outcome and impact, which together define the importance. Proactive risk management improves processes and inhibits supply risks pre-emptively, which is suggestible as it also improves cost efficiency. Reactive risk management accumulates stocks and mitigates impacts post the risk event.

Keywords: inbound supply risk, supply failure, risk management, telecommunications
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Tarjontariskien tunnistaminen
Case OEM Telekom-toimittaja

TIIVISTELMÄ (Abstract in Finnish)

Globalisoituneessa yhteiskunnassa yritykset keskittyvät ydinosaamisiinsa säilyttääkseen kilpailukyvyn, kustannustehokkuuden, ja innovatiivisuuden. Loppuasiakkaalle lisäarvoa tuottavat yritykset ovat entistä enemmän riippuvaisia alihankkijoiden työpanoksesta, joten monimutkaistuvissa verkostoissa erilaiset riskitekijät ovat lisääntyneet huomattavasti. Tarjonnan epävarmuuden lisäämää toimitusriskiä lisää kysynnänvaihteluiden aiheuttama epävarmuus, joka ilmenee asiakkaiden lisääntyneinä vaatimuksina tuotteiden suorituskyvylle ja toimitusajoille. Tarjontaketjun riskit muodostavat dynaamisen ja monimutkaisen kokonaisuuden, jota yrityksen täytyy hallita selviytyäkseen markkinoilla.

Tämä tutkimus pyrkii tunnistamaan ja luokittelemaan tärkeimmät riskitekijät, jotka vaikuttavat toimittajien operatiiviseen toimituskykyyn, toimialakohtaisia tekijöitä korostaen. Case-yrityksen toimintamalli perustuu ostojen konsolidointiin alueellisissa jakelukeskuksissa, mikä suurentaa toteutuneen tarjontariskin haittavaikutuksia. Tutkielman tarjontariski on määritelty toimittajan epäonnistumisena toimittaa tuote haluttuna ajankohtana ostajalle. Toteutuneen tarjontariskin vaikutukset ovat kriittisiä menestykselle. Suorat vaikutukset ovat asiakastyytymättömyys, jälkitilausten kasvu tai pahimmassa tapauksessa myynnin tai asiakkuussuhteen menetys. Tarjontariskit ovat luokiteltuna 1) toimittajariskeihin, 2) toimittajien kokemiin riskeihin, 3) tuoteriskeihin, ja 4) makroympäristön riskeihin. Kaikki neljä riskiluokkaa yhdistämällä päädytään viitekehykseen, jonka avulla pyritään arvioimaan tarjontariskiä tuotetasolla.

Riskeillä on havaittu olevan keskinäisiä riippuvuuksia ja korrelaatioita. Jotkin riskit saattavat vahvistaa toisten riskitekijöiden esiintymistiheyttä tai voimakkuutta. Tutkielmassa selvitettiin tuote- ja toimittajatasoisten riskien korrelaatioita kvalitatiivisella analyysillä. Näistä johdettiin riskien korrelaatiomatriisi, jonka löydöksistä on hyötyä analysoitaessa riskien taipumuksia ja eskaloituvien vaikutusten ennaltaehkäisyä. Matriisin mukaan riippuvaisimmat riskitekijät ovat ylijäämävarastojen kasvu ja ostosyklin kokonaiskesto. Kaikkein selittävimmät tekijät ovat muutokset asiakaskysynnän rakenteessa, tekninen kompleksisuus, ja tuotteiden korvattavuus. Toimittajariskien vaikuttavimmat tekijät ovat yrityksen taloudellinen tasapaino, tavoitteiden ja päämäärien yhdenmukaisuus OEM:n kanssa, sekä alihankkijariskit.

Tässä tutkimuksessa esitellään riskienhallintaprosessi kokonaisuudessaan. Siihen kuuluvat riskien tunnistaminen validin mallin saamiseksi; riskien luokittelu strukturoidun lähestymistavan saavuttamiseksi; riskien arviointi ja priorisointi, minkä perusteella riskienhallintaresurssit voidaan allokoida. Tunnistuvaiheessa määritellään riskitapahtuma ja sen impakti, mikä määrittelee riskin merkityksen. Riskienhallinta jakautuu kahteen osaan: proaktiiviseen prosessikehitykseen, joka ennaltaehkäisee riskejä sekä reaktiiviseen johtamiseen, jonka keinoihin kuuluvat varastojen kasvattaminen sekä toteutuneiden riskien vahinkojen minimoiminen.

Avainsanat: tarjontariski, toimitusriski, riskienhallinta, telekommunikaatiot
Sivujen lukumäärä: 88

Inbound Supply Risk Identification
Case Telecommunications industry

List of Figures

List of Tables

List of Appendices

1 Introduction

Today's global competition forces companies to focus on their core competences (Prahalad and Hamel, 1990) and to align in complex chains and networks (Harland et al., 2003), supplying products and services to end customers. It is argued that it is no longer individual companies, but whole supply chains that compete against each other in the market.

Globalization stretches challenges to new levels. Supply chains have to be more cost effective to remain competitive, while having to serve a more demanding customer base: products and services are required with shorter lead times, more customized and at lower prices. Companies have to follow up technological advancement: product and production technologies can quickly become obsolete. Bureaucracy is also elevated as more foreign legislation has to be taken into account, not to mention political risks. These all increase the inherent risks in the business environment (Harland et al., 2003).

Companies with multinational operations have to be able to assess their risk position in a structured way to avoid unexpected complications that can have cascading effects through the whole network. All businesses engaged in value-adding activities rely on purchased goods to fulfil customer demand (Choi and Krause, 2006) and thus managing supply risk becomes critical to business success. This is an increasingly important aspect of doing business in the global environment.

1.1 Motivation of the study

Risk in general has been a widely researched subject, but risks related more specifically to inbound supply risk is a rather new area of research in academia (Zsidisin et al., 2000). Several authors have contributed to reduce this gap in research, but none seems to have approached the problem from individual item level to provide a framework for practical assessment of the causes of inbound supply risk. In addition, at present the author is unaware of any studies related to inbound supply risk in *a hub operating model*. The hub model has several assumptions and limitations that affect most specifically the impacts of actualized supply risks (see Section 3.1.1: Shortage risk in hub operating model).

Managing inbound supplies is crucial to modern businesses. A clear indication of the reliance on outsourced production is the percentage of purchased parts of total sales. That figure can be very high in many industries, e.g. metals - 45 percent, electricity - 49 percent, machinery - 50 percent, oil - 80 percent (Leenders et al., 2002) and in case of a low value adding distributor the figure is even higher. Managing supply risks is an approach of proactive supply management and improves processes. Since there can be huge amounts of capital tied up in the operations of global supply chains, even a small systematic process improvement can have a significant cost savings effect when implemented globally. Thus, process improvement not only protects from unexpected delays in supply, but also improves cost efficiency. Moreover, fewer inventories are needed when operations are more reliable. Building up inventories is generally thought to buffer against disruptions in supply and peaks in demand. While it possibly does that and provides a better service level, it hides the root causes of operative problems beneath. Echoing to that, a recent study by Kull and Closs (2008) argues that building up inventories may in fact increase supply risk.

This study is very relevant in the modern business environment where networking, outsourcing, and globalization are increasing. Since customers are more demanding, competition is tougher, and risks are increasing in the global environment, it is imperative for the transactions-dependent company to manage and coordinate inbound supply to maintain business continuity. On-time delivery ensures customer confidence, a shorter cash flow cycle, and less tied-up capital. Especially on a global scale, supply failures can have huge profit impacts. For that reason, the continuous development of risk analyses and management strategies is vitally important. In telecommunications industry, supply risks have been even more evident after the 'Great Telecoms Crash' in 2000, which reduced the number of equipment manufacturers and compromised the global availability of many crucially important materials (e.g. Interview E).

In general, creating new conceptual models for managing risk will help mitigate the problems of bounded rationality (Simon, 1957, 196-206 in Silver at al., 1998, 28). Coupled with risk complexity, human decision-makers cannot process all information even if it were available. This is likely to result in sub-optimal decisions in the supply chain. Thus, a decisions-supporting system functions as a tool that forces the user to confront all necessary aspects of supply risk propagating factors.

1.2 Research problem and objectives

This study explores supply risk characteristics of modern company networks from the perspective of a global OEM telecom supplier. The research problem is: **"what are the most relevant causes of operational inbound supply risk from an external supply base that compromise the delivery capability of an OEM supplier, and how can the OEM identify and classify these risk causes on a product level aggregation?"**

The goals of this research are to

1. define and increase the understanding of supply risks and impacts in networks and propose a framework for product level risk assessment,
2. identify and classify the most relevant sources of inbound supply risks, specifically in the hub operating model,
3. discuss the correlations and dependencies of the risk sources,
4. outline the complete risk management process.

Prior research functions as the basis of supply risk identification. The findings are combined into a purposeful classification, suitable for this study. In order to fully represent the nuances of the case company and industry, the model is enriched with case company interviews in order to achieve theoretical saturation, which according to Eisenhardt (1989), is achieved when new interviews do not bring about significant new information. The interviewees are experts and managers working in different inter-organizational functions under the operative branch. Based on literature and the case interviews, a framework is proposed for the assessment of inbound supply risk on product level aggregation. In doing this, the complete process of supply risk management is outlined in the study.

Since companies face risks from internal and external sources and are dependent on each partner in the supply chain (Hallikas, 2003), the risks faced by the OEM's 1-tier suppliers are taken into account as factors that may increase the OEM's overall risk position in terms of its inbound supply. These risks are propagated by external risks from the macro-environment and product level characteristics and sourcing choices. Operational risk sources seem to have significant interdependent relationships. These causalities and correlations are discussed in the empirical part of the research.

1.3 Research limitations and approach

To outline the research scope and limitations, the concept of inbound supply risk and its impacts must be defined. Tang (2006) divides supply chain risks into two categories: disruption risks and operative risks. Operative risks –the focus of this study– are referred to as inherent uncertainties such as uncertain customer demand, uncertain supply, and uncertain cost. Disruption risks are referred to as the major disruptions caused by natural and man-made disasters such as earthquakes, floods, hurricanes, terrorist attacks, or economic crises such as currency evaluation or strikes. The impact of a supply failure is the unavailability of a requested sales item, resulting in the inability to fulfil customer demand. Thus the risk event is a supply failure, the risk-experiencing entity is business, and the outcome is loss of sales or order backlogs, or loss of goodwill or loss of customer account. Another indirect impact, less intuitively, is increased inventory holding cost caused by the hub operating model (see Section 3.1 for discussion). Even though disruption risks have a much greater business impact than operational risks when they transpire (Tang, 2006), the focus of this study is on operative risks. The reason is that they exist inherently contradictory to disruptive risks, have a continuous (yet undefined) probability distribution, and are to some extent *proactively* controllable by the company, whereas disruptive risks are only *reactively* controllable. For these reasons, managing operative risks provides a more fruitful basis for achieving results and also improves efficiency in terms of performance and costs. Disruption risk management is important, but is more concerned with contingency planning and is suggested as a future research area for the case company[1]. Other types of risks that are not considered in this study are e.g. safety, health, and environmental risks. The difference is the entity that experiences the risk: customers and nature. This study is limited to defining supply risk strictly from business point of view.

The view on risk is static and the time horizon is short term. Static perspective always views risk as an undesirable event with a negative impact. A dynamic view would incorporate risk taking by speculation in order to gain profits, which is a common business practice, but there is no profit to be made out of supply failures. From a static perspective, risk management is concerned with minimizing risk occurrence likelihood and mitigating the impacts. The time horizon changes the

[1] For an extensive review on disruption risk in supply chains, the reader is referred to e.g. Tang (2006) and Norrman (2004). Norrman presents a notorious example of the necessity of contingency planning in an article that describes a fire-incident at the site of a sub-supplier of Ericsson's. The unlikely risk scenario incurred losses of over $200 million.

sources of supply risk somewhat. They are more operative in the short term and more strategic in the long term. Long term is concerned with cooperation and alignment of interests between the OEM and its supply base. Long term issues shape the risks in the short term. The view here is on the short term in order to capture the operative risk issues in daily cooperation and procurement cycle with suppliers.

The measurement approach is narrowed down by the complex nature of risk. An exact, or even near, numerical quantification of identified risks and their impacts would require extensive research and a reductionist definition of risk sources. With carefully defined risk measuring instruments, multivariate statistical methods seem promising as quantitative approaches when the research area becomes more matured and well-defined. This study utilizes qualitative data to grasp the manifold levels of the concepts. The research is carried out by conducting exploratory case company interviews.

Supply risk is a phenomenon linked to all companies that are engaged in value adding activities and procure parts or complete sales items from upstream suppliers. The features of supply risk are thus possible to generalize to all similar product-intensive industries like electronics, but each supply chain and each company inside it has nuances of their own. This study is done by interviewing one global OEM telecom supplier and one of its key 1-tier suppliers. In that way, the results are best fit for generalization in telecommunications, but especially the correlations of the risk sources should have fundamental implications on any profit-seeking corporation.

1.4 The structure of the study

This thesis consists of four chapters. The introduction in Chapter 1 includes the general motivation for this type of study and the specifics of the research problem and objectives, with discussion on the taken research approach to study the phenomenon. It also outlines the research scope and limitations.

Literature survey in Chapter 2 begins with background information on the concept of risk, which is defined in terms of its general properties and perspectives. From there the discussion continues by outlining the general process of risk management, concluding to the definition of supply risks and the effects of modern supply networks in the global environment. It can be seen that modern networks have such characteristics that increase risks of a supply failure. The main focus of the chapter is on the identification of supply risk causes, which is done in Section 2.4. The risks are classified into the larger entities of 1) Risks related to suppliers, and 2) Risks related to products. The risks of the macro environment are discussed at more length in Chapter 3.

The empirical research in Chapter 3 begins with the introduction of the hub operating model and its limitations and implications (Section 3.1), which are foremost related to the different characteristics and definition of the impact of a supply failure. Research methods and main findings from the case interviews are discussed in Section 3.2. The framework and dynamics of the causes of supply risks on product level aggregation is represented in Figure n-n in Section n-n. The risk identification process is continued by enriching the classified categories with more details and industry-specific knowledge. The findings that differ from those of the literature survey are highlighted. The risk correlations and causal relationships are discussed in Section 3.4. To wrap up the remainder of the risk management process, the connection to a continuous review loop is briefly looked at in the final section (3.5).

Chapter 4 recaps all the contents of the thesis in a short executive summary in Section 4.1 and highlights the findings and contribution of this study in Section 4.2, in which the study and its implications are related to the research field and the case company. Finally, suggestions for future research are made in Section 4.3.

1.5 Terminology

Some of the more important general and case specific concepts are listed below. The concept of risk is not included here, since it is more fundamental to the study and is discussed at length in the literature survey in Chapter 2.

Hub concept	Hub is a regional distribution centre. Customer orders are placed to the hub and all the items required on the customer specified configuration are procured from internal (company owned factories) and external suppliers to the hub. From the hub, goods are shipped as full configurations to end customers. See Figure 3-1 on page 37 for a graphical representation of the hub concept.

Supply Chain Management (SCM)

Tang (2006): "the management of material, information and financial flows through a network of organizations (i.e., suppliers, manufacturers, logistics providers, wholesalers/distributors, retailers) that aims to produce and deliver products or services for the consumers. It includes the coordination and collaborations of processes and activities across different functions such as marketing, sales, production, product design, procurement, logistics, finance, and information technology within the network of organizations."

Supply Chain Risk Management (SCRM)

Tang (2006): "the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity."

1-tier, 2-tier First-tier, second-tier. The closest supplier to the OEM is called a 1-tier supplier, the sub-supplier to the OEM is called a 2-tier supplier.

Upgrade A capacity expansion project for existing base station sites. Placed as bulk orders to hubs.

2 Risk management theory

This chapter surveys existing literature on risk management in general and specifically related to supply risks of inbound materials. After defining and outlining the concept of risk (2.1), the chapter continues with a discussion of how risks are manifested and augmented by global network structures (2.3) that are becoming increasingly complex. Section 2.2 illustrates the risk management process steps: risk identification, classification, assessment, and management. Section 2.4 discusses what can be learned from existing literature as the factors that increase the probability of inbound supply failures, i.e. the identified sources of inbound supply risk. In the same section they are classified under the constructs of 1) *risks related to the OEM – supplier relationship*, 2) *risks related to products.* Risks related to the macro environment, are discussed in Chapter 3. The factors under these constructs are broken down to sub-factors and discussed in detail. The outcome is a conceptual hierarchical model that represents some of the most relevant risk factors that contribute to operative inbound supply risk. The chapter concludes in a brief discussion of risk management methods in Section 2.7. Managing the identified risks is based on the assessment phase and is a necessary part of the process in order to achieve the targeted overall risk position. The main thrust of this thesis, however, is to further conceptualize the supply risk framework by extensive risk identification. The discussion on risk assessment and management therefore is kept brief on purpose.

2.1 Risk concept and background

Risk as a general concept is very broad. Therefore it is important to define what is meant by risk in each case: what is the perspective, what is the entity that experiences the risk, and what are the risk event, outcome and impact. Perspective-wise, risks can be defined as speculative, static, dynamic, or inherent (Grose, 1987, 31; Byrd, 1982). Speculative risks are discretionary to the entity that experiences the risk; for example an investment in equities. Static risks, or insurance risks, are constant risks that are related to unwanted scenarios *such as supply failures* and they can result in losses only. Dynamic risks are varying and unpredictable conditions, created by humans or nature, such as earthquakes or economic crises. Inherent risks are harmful factors that inevitably belong to operative phenomena (Engblom, 2003, 23) such as uncertain customer requirements (Wu et al., 2006).

The entity that experiences the risk and the defined risk event are related to each other. For example, if the risk event is a supply shortage, the entity that experiences the risk event is business. Other entities might be affected by the risk event as well: e.g. a booked transportation may need to be cancelled, but the impact of that might not be significant. However, that illustrates how one risk can result in another. For that reason, the risk event and the entity that experiences the risk are closely related. This is an aspect of risk definition that was not come across in literature by the author.

A risk event is any scenario with some probability of occurrence and an outcome with some impact. In case of inherent or static risks, the impact is of negative sort. According to Herz and Thomas (1983), risk means uncertainty and can be defined as the possibility of loss, injury, disadvantage or destruction. Fundamentally, risks manifest lack of predictability of structure, outcomes and consequences in a decision or planning situation (Hallikas, 2003). Chapman and Ward (1993, 7) see risk as any factor that can affect the performance. When the risk event takes place, its outcome and impact vary in nature and significance: the outcome can be constant or it can have a distribution depending on some other defined factor. For example, the impact of all ice cream being sold out depends on the warmth of the weather that day. The significance depends on what is thought to be important by definition – the impact of the ice cream shortage may be greater to a five-year old than an adult. There are a multitude of studies of how to assess all of these main aspects: the event, its causes, outcome and impact.

According to the above reasoning, inbound supply risk is an event that is defined as the supply failure of products or materials from an internal or external supplier. That event can be the result of an endless parade of causes, some of which are more prominent than others. As supply management is the task of the operative function, it can be concluded that inbound supply risks are static and exist inherently, as has been stated by several other authors as well (e.g. Zsidisin et al., 2000; Harland et al., 2003). The outcome of supply failure is the inability (of the buying company) to fulfil customer demand (Zsidisin et al., 2004), resulting in both direct and indirect impacts. The direct impacts include order backlogs or loss of sales, and loss of customer and stakeholder goodwill. As will be illustrated in Section 3.1 (Implications of the hub operating model), the indirect impacts can increase inventory carrying costs and result in suboptimal resource allocation of risk management efforts.

As discussed above, a risk can have a variety of causes that ultimately incur the supply shortage. It is impossible to measure the probabilities of each individual direct cause of the event. For example, it makes no sense to assess all possible causes of a traffic accident. Instead, the researcher should look for signals of the root causes –or leading indicators– that propagate the likelihood inherently, and use these as a proxy for risk estimation. Hallikas et al. (2002b) represents a framework that functions as the foundation for risk estimation (Figure 2-1).

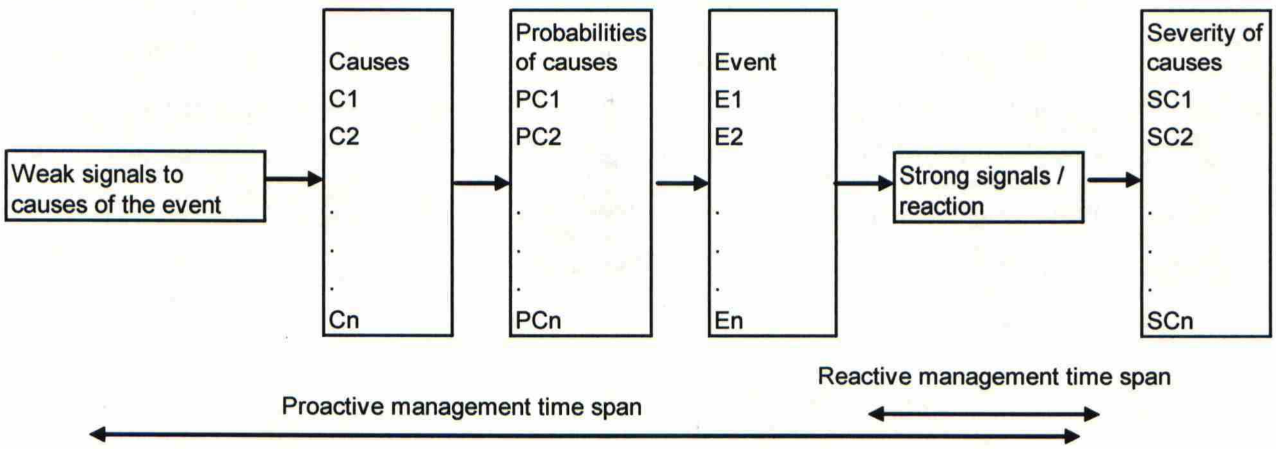

Figure 2-1: Risk assessment framework (Hallikas et al., 2002b)

The concept of probability is important when talking about risks. Probability is generally divided into objective and subjective interpretations (Engblom, 2003, 17). Objective probability is typically divided into either frequency or propensity interpretations (Lagerspetz, 1981). Frequency is the number of occurrences in a group, and propensity is based on knowledge of the parameters of the underlying trial subject, e.g. the throwing trial of a dice. Subjective probability on the other hand is the strength of belief in a probability based on available information or intuition, which is typically the case in business decisions (Engblom, 2003, 17). Kreps (1990) argues that the difference between the concepts of risk and uncertainty is that *risk* is based on objective and *uncertainty* on subjective probability. According to Engblom (2003, 17) the probability and outcome of a risk together define the risk.

Literature often discusses risk attitude. Whilst they are acknowledged and can have an impact on the decision systems of a supply chain, they are not included in the scope in this study. This is because risk taking attitudes are more suitable to the study of human behaviour, and especially when the risk perspective is static, the only logical risk taking attitude is risk aversion.

2.2 Risk management process

Risk management process is a method for managing any defined risks. It starts with the identification of potential risks, which can be industry- or company specific. After being identified, risks are assessed by different measurement methods – mixing qualitative and quantitative data. If possible, this phase should include the estimation of impacts. Based on these assessments, risks are assigned significance and priority. According to Engblom (2003, 19), the goal of risk management process is to ensure avoid unbearable risks and notice changes in circumstances that posit new threats to the continuance of business. He continues by stating that risk management also enables better decision-making. Harland et al. (2003) provide a supply network risk tool that describes the whole process of risk management, depicted in Figure 2-2.

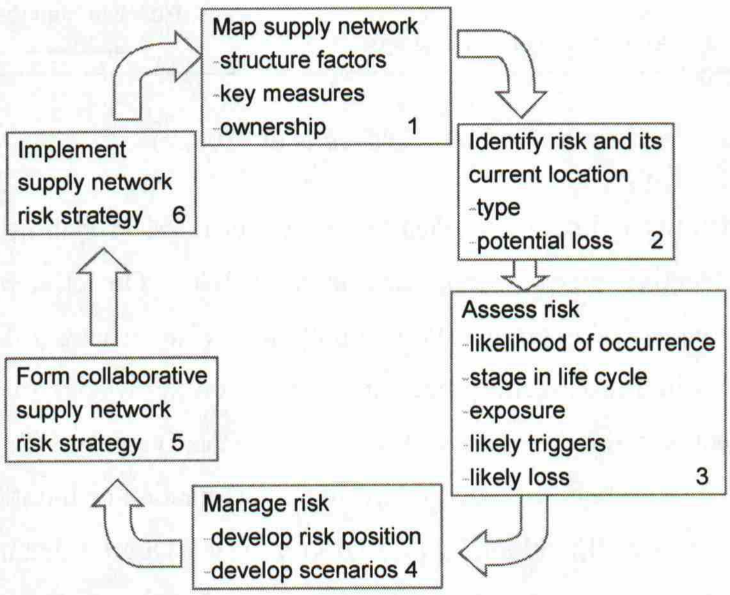

Figure 2-2: Supply network risk tool (Harland et al., 2003)

Measurement and assessment of a risk is the prerequisite for its management, because it is necessary to know which risks are worth addressing. A risk is more prevalent when it is both likely and has a great impact (Chapman and Ward, 1993, 7). Analogically; it is safer to put on a helmet on a bus trip than not, but the risk does not warrant the inconvenience for the majority – even though the impact might cost the user's life. At best, incremental risk management efforts should be based on increasing marginal utility of reducing the risk likelihood and the effectiveness of impact mitigation (e.g. how well the helmet is believed to reduce the severity of causes in case of an accident). The higher the likelihood and the greater the impact, the greater the marginal benefit for managing that risk. In contrast, wearing a safety belt would warrant the (lower) inconvenience and the higher level of impact mitigation. In that sense, the choosing of risk management methods is affected by their effectiveness during reactive risk management. The increasing marginal utility of risk management as a function of probability and impact is depicted in Figure 2-3 below.

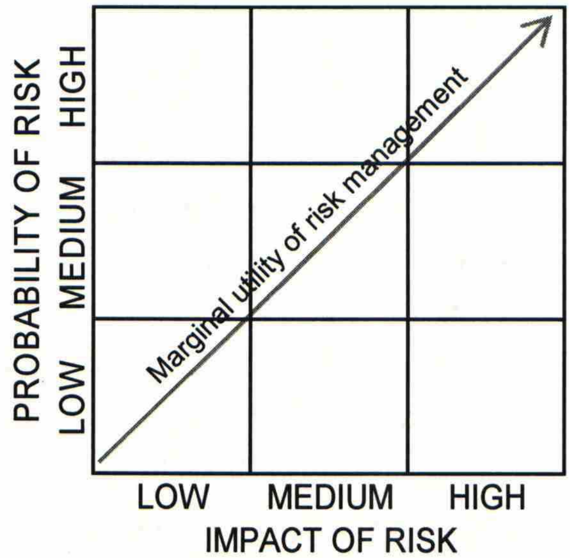

Figure 2-3: Probability and impact of risk; and the increasing utility of risk management

The assessment phase is as crucial as the correct identification of relevant risks. Correct identification equals to effectiveness – right things are measured. Correct assessment equals to efficiency – right things are measured reliably. The diversity and dynamics of risks (e.g. Hallikas, 2003) challenge the measurement of probabilities, which are in this case mostly based on subjective probabilities, but the model should however provide a useful representation of the real world when it is based on expert opinions and intuitions.

The *management* phase takes place in two parts. The proactive time span is the part of risk management where risks are prevented by minimizing their likelihoods of occurrence, and transferring or spreading them by diversification. The reactive time span starts after the risk event actualizes and its outcome impact is mitigated. Finally, the process concludes in a feedback loop and continuous review. In corporations, this means defining the process, process owners for continuous performance review, and the triggers that initiate a more thorough one-off analysis.

The risk management process of inbound supply risk includes all of the above mentioned phases. The final phase, risk management, is basically very similar to implementing best practices or continuous improvement of operative processes. This sort of proactive supply management reduces the likelihood of any potential cause that can result in supply failures. This view on supply risk management is similar to what Smeltzer and Siferd (1998) state: "proactive supply management is risk management."

In order to assess a company's operative effectiveness, it is a useful assumption to include only the time span of proactive risk management. What this means in practice, is the assumption of zero inventories. When there are no inventories, the fundamentals of supply capability -the capacity and the constraints- become visible. With zero inventories, the only way that performance can be improved is through process improvement – be it new investments or more effective and efficient ways of handling things. The more effective the company is, the better it manages the root causes of operative instability – or supply risks. Accumulating inventories is a passive –or reactive– method of managing supply risks. When proactivity is at its highest possible level, the service level can be improved only with higher inventories, and that becomes the opportunity cost of the inventory carrying charge.

2.3 Supply risks and impacts in global demand-supply networks

Modern companies have aligned in supply chains and networks. Outsourcing has evidently become the prerequisite for competitive advantage for many companies (Prahalad and Hamel, 1990), while at the same time increasing the exposure to uncertain events with suppliers (Zsidisin et al., 2000). According to Harland et al. (2003), managers need to identify and manage risks from a more diverse range of sources and contexts. This section discusses supply risks that are general to the classifications presented later on, and how networking augments risk.

There is no clear agreement on what results as a risk in supply networks or in the supply base specifically. Choi and Krause (2006) argue that reducing supply base complexity actually increases supply risk when the buying company has less choice and less sources. Also too high complexity of the supply base will also result in unsustainable inflexibility and cost because of increased resources needed for its management. This view is in agreement with Harland et al. (2003) who state that the complexity of the supply network augments supply risk. The increasing complexity of supply network arises from many sources, but the key drivers are increasing product and service complexity, e-business, outsourcing, and globalization (Harland et al., 2003). By outsourcing non-core activities, companies attempt to reduce costs and become more effective by focusing on their core competencies (Prahalad and Hamel, 1990). Activities that add no value to the end product or service, or the company is less effective than its competitors, are divested. Resources seek optimal allocation and division of tasks: while some outsource, others insource or expand to areas of their core competence to gain competitive advantage. Typical examples of outsourced activities are administrative functions like payroll calculation or accounting.

When a company is functioning on a transactional basis (i.e. purchasing input resources from external suppliers instead of in-house production), especially the closest link to the end customer can be completely dependent on supplies from the upstream. This link faces the cumulative probability of a supply failure, accrued all the way from the upstream network[2] beginning with the global availability of raw materials. In this study, risk is assessed from OEM perspective, including aspects of 1-tier supplier risks if these are expected to affect the OEM. Figure 2-4 is a simplified representation of a tiered network structure, with material flow downstream, and information flow upstream.

[2] Intuitively-the further upstream the company is in the demand-supply network – the larger and more homogeneous the customer base is. Thus, the asset specificity and demand risk are lower. Conversely, the lower downstream the company is in the network, the higher the asset specificity, customer heterogeneity, and overall demand/supply risk.

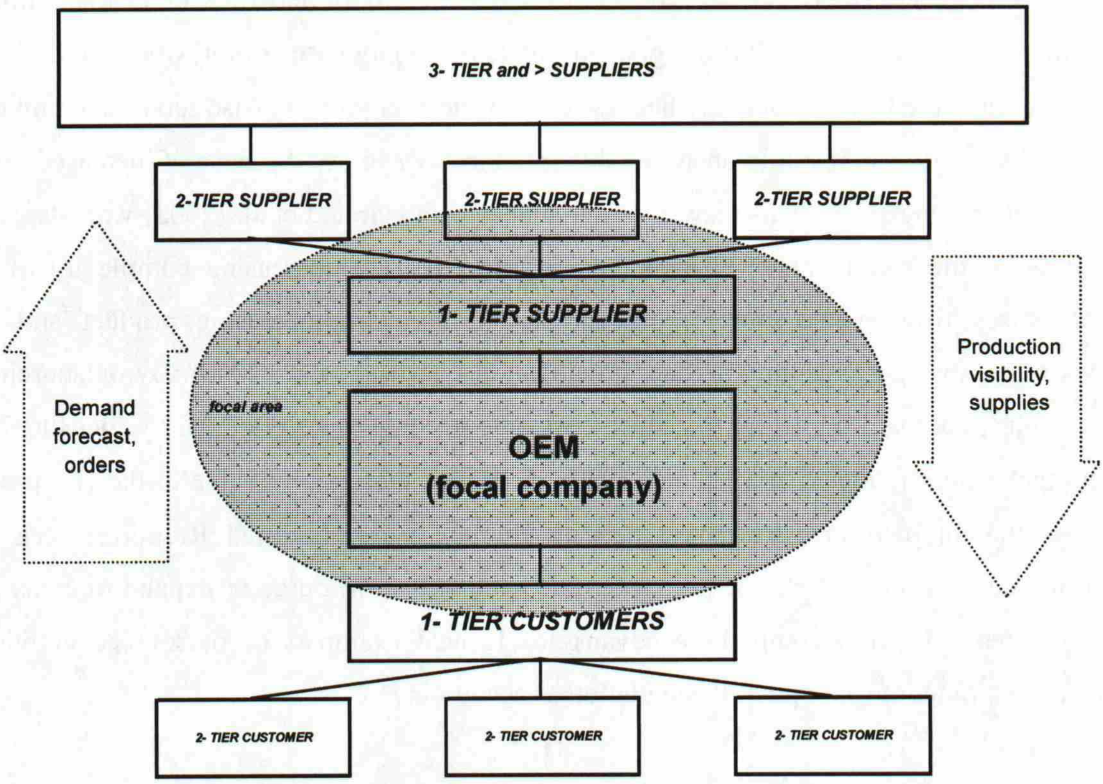

Figure 2-4: A simplified depiction of a tiered supply network

The definitions of supply failure are fairly uniform in literature. Zsidisin (2003b) provides a grounded theory definition of supply risk:

> "...supply risk is the probability of an incident associated with inbound supply from individual supplier failures or the supply market occurring, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety."

A supply risk can occur at any stage in the supply network. Zsidisin et al. (2000) list some examples of the more extreme consequences: shut-down of production lines due to the lack of incoming materials from a supplier. I.e. flows of materials can stop at any stage, causing domino-effects throughout the supply network, because of schedule dependencies. In this study, supply risk is understood as the general unpredictability of all inbound flow of materials (and services) to the buying firm, excluding the threats to customer life and safety, which in the author's opinion are more concerned with outbound supply risk and quality assurance of the product. To further classify the types of supply failures in supply chains, Tang (2006) divides them into two categories: disruption risks and operational risks. Operational risks are referred to as inherent uncertainties such as uncertain customer demand, uncertain supply, and uncertain cost. To some extent, operational risks are inherently present in business environments (Zsidisin et al., 2000). Disruption risks are referred to as the major disruptions caused by *natural* and *man-made disasters* such as earthquakes, floods, hurricanes, terrorist attacks, etc. or economic crises such as currency evaluation or strikes (Tang, 2006). Other examples of disruption risks are tornadoes, blizzards, fires, accidents, and illnesses (Zsidisin et al., 2000).

The impact of a supplier's failure to deliver inbound purchased goods or services can have a detrimental effect to the purchasing firm and subsequently throughout the downstream supply chain. The purchasing firm will usually suffer immediate damage from production [or delivery] delays when a loss associated with critical supplies occurs, or when a supplier provides supplies or components that do not meet quality specifications. (Zsidisin et al., 2004) In addition to increasing outsourcing, globalization of operations stretches the challenges of networks to new levels. Companies have to be even more cost-efficient and responsive to more demanding customers: products are requested with shorter lead times, more customized (e.g. mass customization), possibly in higher volumes, of higher quality, and at competitive prices. Product specifications change in response to customer needs. This, together with technological change, drive down product life-cycles, making the winning combination even harder to achieve. In order to survive and not lose business to competitors, companies need to be flexible. Besides flexibility, companies have to be agile and adaptable to remain competitive (Hau, 2004). They need to scan the competitive environment proactively and adapt to unavoidable changes when needed through for example disposals, outsourcing, or labour base resizing. Networking and globalization introduce new risks to operations, because of the increased exposure to transactions between separately managed companies with different financial goals, often differing also in location and culture.

Although risk itself has been researched in abundance, risk management in networks has not been a popular research area until recent years (Hallikas, 2003; Zsidisin et al., 2000) and there exists minimal research on how purchasing organizations assess risk on inbound supply (Zsidisin et al., 2004). Hallikas (2003, 48) points out that there are a multitude of risks faced by networked companies; risks whose direction, probability and impact vary. For that reason, it is important to filter out such risks that can occur, but do not contribute enough to inbound supply risk in order to be utile to mitigate (as illustrated in Figure 2-3). Lindroth and Norrman (2001, 301) have found two typical research approaches to risk management in supply chains:

1. Conceptual exploratory research to grasp the structure of the complexities in its management, (the topic of this study, with emphasis on assessment)
2. Quantitative models optimizing or understanding consequences of clearly defined risk sharing instruments.

The perspective to risk is typically that of the purchasing company (Lindroth and Norrman, 2001; Hallikas, 2003). Hallikas (2003) also argues that an important addition to this is to take supplier perspective into consideration, because risks in networks have interdependent effects. Since risks are common to the whole chain -not just individual companies- it is important to distribute risk by sharing and transferring it fairly among the partners. Carrying risk should be rewarded, but the problem is the complexity of the concept: it is impossible to gauge the exact contribution of an individual factor's probability and impact, because risks depend on unforeseeable circumstances with unknown probability distributions.

2.4 *Identification of inbound supply risk sources*

This section provides a view on the commonalities of some of the prior studies in the area of inbound supply risk. The review is not exhaustive, but the sources include a variety of books and articles published in acknowledged journals. The most important aspect of studying risk management is to exhaust the list of the most relevant risks, so that no important aspect is ignored. The main function of the classification is to be used as a check-list tool for a continuous supplier audit. In the discussion from here on, supply risk is assumed to take place as part of companies engaged in transactional relationships in a networked structure.

2.4.1 Risks related to suppliers

This section presents some of the most prominent risks related to suppliers, and the risks that the 1-tier suppliers face in their relationship with the OEM. Some of the findings are classified in Table 2-1 and discussed further in the following paragraphs.

Table 2-1: Risks related to suppliers (from OEM perspective)

Type of risk	Description
Supplier capacity and flexibility (Zsidisin et al., 2000)	Low capacity – inability to keep up with high volumes Low flexibility – inability to keep up with demand changes High capacity utilization – inflexible supply Low capacity utilization / too high flexibility – unsustainable costs
Financial stability (Zsidisin et al., 2000)	Financial instability increases uncertainty in supply
Power structures (Zsidisin et al., 2000)	Dependence on the supplier
Person risks (Hallikas, 2003)	Availability of skilled personnel Dependency on key personnel Personnel changes in company
Complexity of supply base (Choi and Krause, 2006)	Both too low and too high complexity increase supply risk
Risks faced by 1-tier suppliers	See Table 2-2

Supplier's capacity and flexibility

A supplier's capacity is one of the more obvious components of risks from sourcing. It is the production or sourcing capability of the supplier, which equals to the amount of available equipment and labour, in addition to what the supplier can purchase from sub-suppliers. In other words, capacity in one time unit equals to the amount of products that can be made available in it. Reserving capacity, i.e. allowing the flexibility of utilization to increase, in anticipation of future demand has its trade-offs. It may be difficult to utilize excess capacity during order declines (Cyert and March, 1963 in Zsidisin et al., 2000). Having excess capacity does not pay off unless it is contractually enhanced or compensated for.

Flexibility is closely linked to capacity. Theoretically, flexibility equals to the amount of slack capacity: if the capacity utilization is 80 %, then there is flexibility to increase production by the remaining 20 %. Practically, 100 % capacity utilization is not realistic. A supplier's maximum flexibility is dictated by the break-even volume in production – or how much slack capacity can be maintained profitably. Naturally, a supplier's capacity has a significant effect on downstream availability risk. Flexibility and capacity are important in offsetting demand variations. This becomes more pronounced upstream in the chain, because of the bull-whip effect (Lee et al., 1997). The bull-whip effect distorts demand information when upstream partners lack visibility to end customer demand and tend to amplify variation in order amounts to the upstream.

Financial stability

Another important feature of supplier-related risks is financial stability, which is called "business risk" by Zsidisin et al. (2000). Supply risk occurs when a supplier is in financial hardships and the purchasing organization has a certain degree of dependence on that supplier. The financial performance of a supplier is necessary to monitor in the selection phase as well as in a maintained relationship.

Power structures

Financial stability is closely linked to power structures and risk sharing in the supply chain. In cooperative business relationships, all partners' risks are interdependent (e.g. Hallikas, 2003). Asymmetries in the relationship can result in supply risk. The more a supplier depends on the OEM, the higher its discontinuance risk if end customer demand collapses. The OEM then has more bargaining power, and can negotiate lower prices, but it also increases its own inbound supply risk. If the supplier's business depends on one large customer (the OEM) it cannot withstand demand instability or other disruptions, which could result in discontinuance of the business. That in turn would result in the OEM being out of supply.

Power structures and bargaining power are important concepts. Zsidisin et al. (2000) point out the importance of relative power associated with capacity in a case example they studied. The relative power relates to the percentage sales of total sales (or percentage of purchasing of total purchases). The buying firm should be aware of the percentage sales volumes (and the percentage of slack capacity) the supplier has to its prospective or existing customers. For example, if some other customer accounts for more than 75% of the supplier's turnover, the purchasing firm should incorporate the risk of shared capacity into its risk management plan. If the other customer was to increase its demand, the buying firm might be out of an adequate source of supply. (Zsidisin et al., 2000)

The power that a purchasing firm exerts towards it suppliers (and vice versa) is a critical factor in risk analysis. Power structures are difficult to measure. Clearly, if the purchasing firm follows an exploitative spot purchase strategy -as Kraljic (1983) suggests for standard parts with good availability- then the supplier is unlikely to be loyal either. In a strategic alliance, the purchasing firm should pay attention to its suppliers' customer base and the amount of slack capacity reserved for it.

Complexity of the supply base

An important aspect of risks related to suppliers is the complexity of the supply base. Choi and Krause (2006) define supply base as the part of supply network that is actively managed by the buying company. The complexity of the supply base they define in terms of 1) the number of suppliers in the supply base, 2) the degree of differentiation among these suppliers, and 3) the level of inter-relationships among the suppliers. In the recent decades, the trend is towards outsourcing from a reduced number of suppliers, which according to Choi and Krause (2006) can sometimes lead to increased supply risk. According to Kraljic (1983), the optimal number of suppliers or the optimal level of cooperation for individual items is based on the product's characteristics. In the purchasing portfolio approach, bulky items are sourced from several suppliers or open market transactions; and more complex, strategic items require closer collaboration with fewer suppliers. According to Kraljic (1983) having few or only one strategic supplier increases control, improves visibility and may have lower costs. However, the risks associated with single sourcing are many. There is more discussion in Section 2.4.3 about how risks of single sourcing of products affect supply risk.

According to Choi and Krause (2006), the complexity of the supply base has a quadratic relationship with supply risk: reducing the complexity so that the buying company is reliant on single sources from suppliers that have similar technologies and little interaction between them, it is more vulnerable to negative events. It is also exposed to the risk of not having access to new and varied technology. On the other hand, high supply base complexity can also increase supply risk because of increased challenges of coordinating all the suppliers. These propositions lead to the conclusion that supply base should be coordinated and managed by the OEM in order to create a situation where its supply risk is on an optimal level, instead of blindly reducing the supply base complexity to any extreme.

2.4.2 Risks faced by 1-tier suppliers

There are risks that are implicit to 1-tier suppliers. Because the OEM's risk is heavily influenced by the risks faced by its suppliers, it is important to incorporate their risk factors as well. This is increasingly so, because there is a tendency to shift responsibilities more and more to the 1-tier suppliers and end customers must be convinced that the supply network is as effective as it was traditionally when production was done in-house (Hallikas, 2003, 37). Some general risks faced by 1-tier suppliers, related to *risks of networking*, are listed in Table 2-2. The listing is a modification from Hallikas (2003), incorporating findings from Zsidisin et al. (2003a). Hallikas (2003) has studied two case supplier networks in metal and electronics industries. Two OEMs and several 1-tier suppliers were included in the study. According to Hallikas (2003, 36) these factors are possible rather than evident.

Table 2-2: Risks faced by 1-tier suppliers (modified from Hallikas, 2003, 37 and Zsidisin et al., 2003a)

Risk Factors	Perceived risks
Position in the network / power structures	Asymmetry in relationship Availability of profitable customers Dependency on the customer Level of depth in relationship with customer Risk transfer to supplies Willingness and capability to take greater responsibility in the network
Technology (product and production)	Asset specificity of technology Flexibility of technology Selection of technology Compatibility of IT-systems <-> co-operation
Co-operation	Compatibility of IT-systems Delivery reliability Forecast accuracy Information transfer with customers Information transfer with suppliers Reliability of own suppliers Shortening delivery times
Finance	Knowledge of total costs Level of working capital tied up in inventories Pressure for price reduction Transfer of buffer stocks to suppliers
Person risks	Availability of skilled personnel Dependency on key personnel Personnel changes in company

Networked companies have roles and competencies reflect the strategic intent of their core competences that should be aligned with the network strategy. Current trend is the shift of responsibilities to suppliers in terms of investments, inventories, and materials management, but their willingness to respond is uncertain and the understanding of the requirements is not always clear. These increase supply risks, while at the same time the OEM has to convince end customers that the structure is effective. (Hallikas, 2003, 37-38)

Depth of the relationships and asymmetries in the sizes of the corporations cause unhealthy dependency and uncertainty. SMEs (small and medium sized enterprises) may have difficulties coping with the requirements of global buying companies, but might have no other choice if their resources are not sufficient to maintain several customers. 1-tier suppliers may have difficulties finding profitable customers, and their small size might also fend off 2-tier suppliers if the volumes are not promising. One of the greater threats is the entry of large competitors. (Hallikas, 2003, 38)

Technological aspects have direct relations with operations. There are pressures to invest in modern technologies, but customer specific investments increase risks and the utilization of new technologies causes uncertainty. The utilization of IT has been considered a significant success factor, and is currently seen as an increasing risk, when many incompatible systems exist and the implementation of new ones is expensive and challenging. The co-operation between companies was thought be largely dependent on the information systems. (Hallikas, 2003, 38-39) If the information systems are incapable of transferring right and timely information, delayed and distorted information flows (e.g. the demand forecast) increase the bull-whip effect (Lee et al., 1997). This can result in poor production planning and control systems in e.g. smaller companies, resulting in uncertainty in deliveries, i.e. supply risks to the 1-tier supplier, coupled with the continuously shortening lead times. The information delays and distortions arise mainly from 2- and 3-tier suppliers, and for that reason good co-operation to ensure delivery capability is an essential factor for reliability and quality in the networks. (Hallikas, 2003, 40)

Technological aspects are related to financial issues as well. The transfer of investments to suppliers is a high risk in terms of technology selection: if the invested technology very specific to the customer, it may have no use elsewhere. According to Hallikas (2003, 40), information about investment need for future technologies are attempted to be given to suppliers. The opportunistic behaviour on OEM side would include forecast manipulation; high volumes would be communicated in order to get the supplier to invest.

Financial issues are closely related to cost targeting. According to Hallikas (2003, 40), the knowledge of total costs in order to manage and control product costs was thought to be an important aspect, because in open cost structures the distortion of production costs in order to achieve a better price is an unlikely but possible risk if a supplier behaves opportunistically. These factors may increase risks of networking, but they seem unlikely to represent high supply risks at least in the short term. More concerning as regards supply risk is purchasing based on unrealistic cost targets and the pushing down of prices in favour of service and quality. The lack of total cost thinking in purchasing was considered a risk by both networks studied by Hallikas (2003, 40).

The main concern in person risks was thought to be the existence of skilled labour. The time it takes to train new personnel was found to be significant. The risks are escalated when critical knowledge is reliant on a few experts whose replacement would be very hard. These issues were believed to have potentially serious consequences. (Hallikas, 2003, 39)

2.4.3 Risks related to products

The risks discussed under this heading are based on the fact that they are either directly caused by a specific product's characteristics, or alternatively, can be indirectly assigned to the product. For example, demand could be thought of as an external risk, related to the operating environment, but since it is the product that is demanded, demand risk can be assigned to this category. Looking at inbound supply risk on item level, instead of some more aggregate measure, enables analyzing aspects that would be left out otherwise. An individual supplier that provides several products is assumed to have different risks for different products, because of the specific requirements and composition of each product.

The overall risk of product supply is dependent on e.g. the number of distinct SKUs (stock keeping units) and the complexity of the products (Harland et al., 2003). Some large manufacturing companies and military organizations carry more than 500 000 distinct items in inventory (Silver et al., 1998) and thus inevitably carry a burden on inventory management. According to Harland at al. (2003), the product (and service) complexity is increasing due to increasing demand for product performance and variety, combined with more complex product and process technologies. They list several dimensions of complexity that affect supply networks (Table 2-3).

Table 2-3: Dimensions of product and process complexity (Harland et al., 2003)

- Scale, - Technological novelty, - Quantity of sub-systems components, - Degree of customization of components in the final product, - Quantity of alternative design and delivery paths, - Number of feedback loops in production and delivery system, - Variety of distinct knowledge bases, - Skills and competencies incorporated in the product package,	- Intensity and extent of end user involvement, - Uncertainty and change of end user requirements, - Extent of supplier involvement in the innovation, - Transformation process, - Regulatory involvement, - Number of actors in the network, - Web of financial arrangements supporting the product/service, - Extent of political and stakeholder intervention

Each of the dimensions can be an issue for supply risk; e.g. customization, product alternatives, and the change of customer requirements. The number of actors in the network was included in the first subsection of risks related to suppliers under the discussion of the complexity of the supply base. On product level this means the complexity of the supply base for a particular product – 1-tier suppliers are likely to source different products from the supply base in differing complexities of arrangements. The risks that appear to be the most relevant ones related to products are listed in Table 2-4. These risks are discussed further in the following paragraphs.

Table 2-4: Risks related or assigned to products

Type of risk	Components of the risk	Further breakdown of causes
Supply risks related to a product's sourcing	Single / partnership / multiple sourcing (Hallikas et al., 2002)	Locking in on an old technology Inflexibility in choosing the best technologies for customer projects Price escalation risk (supplier opportunistic behaviour in single sourcing) (Treleven and Schweikhart, 1988)
	Product composition (Kraljic, 1983)	Technical complexity Scarcity of raw materials from upward supply network
	Sourcing channel (Johnson, 2001)	Geographical separation between demand and supply
Demand risks	Technological change	Obsolescense of product design or production processes/equipment (Zsidisin et al., 2000)
	Demand fluctuations, volume and unpredictability	Exacerbating covariate effect on all other types of risk (Johnson, 2001)
Quality problems	Cascading effects downstream (Zsidisin et al., 2000)	

Product sourcing

The literature on risks related to products, typically discusses risks of single vs. dual or multiple sourcing (e.g. Hallikas et al. 2002; Treleven and Schweikhart, 1988; Kraljic, 1983) or uncertainties in demand requirements (e.g. Zsidisin et al., 2000). Single sourcing of a product, compounded with technology considerations, can be an obstacle for a continuous flow of supplies. Single or partnership sourcing means that the product is bought from only one supplier and that it does not have an alternative supplier in use. The technical complexity of a product's composition is directly correlated with its supply risk level. The more there are sub-assemblies and components and the scarcer and longer their sourcing channels are, the higher the risk of supply disruptions. Kraljic (1983) calls this sort of items bottle-neck items. If at the same time these items are strategically important to the buying company, the risk impact of a supply failure grows significantly. Single sourcing also includes the risk of locking in on an old technology (Hallikas, 2003). This can become very costly if large investments have been made and the chosen technology appears to have been the wrong choice.

A typical multinational company practices "off-shore" global sourcing from low-income countries to utilize cheap labour rates. The long lead time caused by the transportation exacerbates all supply risks (Johnson, 2001). Especially, if off-shored items are heavy, transporting requires ocean freight, which increases lead time further and reduces visibility of the shipment status. For ocean freight also the lead time variance is high.

Technological change

Supply risk can occur due to technological change (Robertson and Gatignon, 1998; Walker and Weber, 1984 in Zsidisin et al., 2000). It can be challenging for suppliers to maintain state-of-the-art technology. New innovation may render current technologies obsolete in a blink. Technological change drives down product life-cycles sometimes unexpectedly. Technological change is driven by market demand. Companies compete for the same customers and thus design changes are made constantly to better meet the dynamic customer requirements, which are each day more versatile and requested with shorter lead times (both industrial and consumer markets). Changes in the end product affect sub-assemblies and raw materials, having further implications to the upstream network (Zsidisin et al., 2000). Supply risk occurs when the supplier is unable to make the required changes in product design or production processes in order to meet the demands of the purchasing company. Depending on the extent of change, in the extreme case, older product versions can become obsolete. Optimal redesign would be compatible with other versions of complementary products. If not, redesign increases risks of both shortage (specifically while in implementation phase) and excess costs. Technological change also concerns production technology. If suppliers are not able to adhere to continuous improvement, changes in production technology can drive up costs, reduce product competitiveness, and increase lead times (Zsidisin et al., 2000).

Single sourcing (or partnership sourcing) and technological risk

Single or partnership sourcing means procuring a product from only one supplier. According to Hallikas et al. (2002), with single sourcing the buying company takes the risk of locking in on an old technology. It does not have the option of choosing the best possible supplier at the last minute to suit all the technological needs of a particular project or product. On the positive side, the buyer has greater access to technological knowledge and is more likely to be involved in mutual development efforts. Treleven and Schweikhart (1988) argue that a buyer can maintain access to various potential sources in the industry through multiple sourcing of product development – and still derive the benefits of single sourcing of the supply.

Price escalation risk

Single sourcing carries the risk of supplier's opportunistic behaviour, in e.g. pushing up the price if the buyer has no other way of obtaining that product (Treleven and Schweikhart, 1988). Nowadays it is believed that this can be avoided with partnership sourcing, which means that both the supplier and the buyer work together to reduce the real cost, which is also believed to lessen the transactional costs (Hallikas, 2002). This is closely linked with early supplier involvement in design processes and value engineering. The purpose of value engineering is to define adequate level of quality in terms of product characteristics. This resembles Crosby's quality ideology, which defines (product) quality as "conformance to requirements, not elegance" (Evans and Lindsay, 2005, 108).

Quality risk

According to Zsidisin et al. (2000), quality risk can have a significant effect on the purchasing company, with the effects cascading downstream. This is due to each link in the chain being dependent on the quality of the upstream. What causes bad quality, can be e.g. lack of capital equipment maintenance, lack of training in quality principles and techniques, and damage during transport and handling. The cost of bad quality can tax a heavy weight on the OEM supplier.

Demand risk

Demand fluctuations and uncertainty in demand requirements exist inherently in supply chains (Wu et. al, 2006). Demand fluctuations seem to exacerbate most other types of risks, like supply risk. Notionally, if demand was steady and the volume was reasonable, there would be no significant operative risk of supply. The main source of supply risk would be due to disruptions: fires, earthquakes, terrorist attacks, and such. As demand risk (fluctuation, volume, unpredictability, etc.) always seems to exist, operative risks become relevant to tackle. Fluctuation and volume are partly dictated by the amount of customers and the heterogeneity of their needs. They also depend on the industry and product characteristics: for example, poor product substitutability and high customer specificity increase supply risks, driven by demand characteristics. The unpredictability is dictated by the level of information sharing, and forecasting is what attempts to minimize it. How well forecasting succeeds, depends on how long in advance it is provided, and how accurate it is. Effectively, forecasting is a risk management tool: it is a proactive method to minimize the risk probability (not the impact). The goodness of forecasting is measured by forecast accuracy, which is crucial for companies to be able to respond timely to customer requirements.

2.4.4 Risks of the macro environment

Supply risk factors of the macro environment are rather uncontrollable especially in the short term. They can have significant effects on operative efficiency. These are quite general risk issues, some of which are faced by companies in any industry. They include different risk environments: legislative, political, bureaucratic, business, operative, etc. These issues are discussed in the case study section (3.3.4), because the majority of the findings are based on the empirical part of the research.

2.5 Classification of supply risks

Why do risks need to be classified? There are countless numbers of inherent risks in doing business (Rieley, 1999) and they are merely augmented by the complexities of network structures (Harland et al., 2003). Classification brings a structured approach to understanding the root causes, and different risk types require different approaches in order to be effective. Some risks may be simple to identify and measure, while others are less intuitive and good estimates are difficult to achieve (Rieley, 1999).

One of the earliest risk classifications was done by Kraljic (1983). He made an important contribution to supply risk management by introducing the purchasing portfolio (Figure 2-5), which is a 4-matrix juxtaposing the importance of purchasing and the complexity of the supply market. Kraljic assesses supply risk by availability, number of suppliers, competitive demand, make-or-buy opportunities, storage risks, and substitution possibilities.

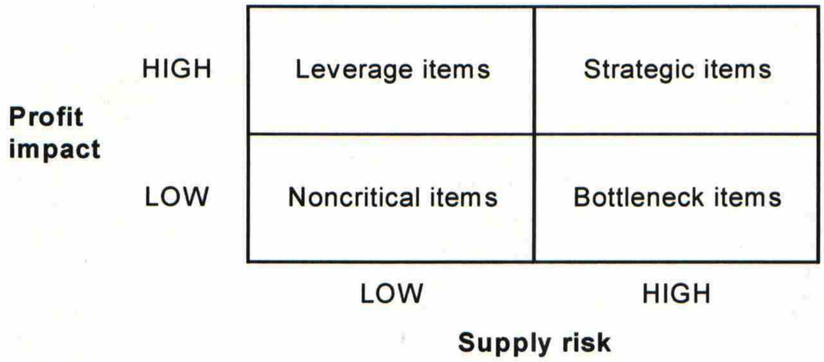

Figure 2-5: Kraljic's purchasing portfolio (1983)

Johnson (2001) argues that risks in networks fall into two broad categories, demand and supply risks. He mentions demand risks like seasonality, volatility of fads, new product adoptions, short product life, etc. As examples of supply risks, he lists manufacturing and logistics capacity. As a catalytic feature, he notes that long (geographical) lead times between demand and supply exacerbate all of the risks.

The argument that the two broad categories of network risks are demand and supply risks, seems plausible. Also Wu et al. (2006, 350) have noted that risks exists inherently in supply chains and can manifests itself as uncertainty in demand requirements. As risks that can be classified under supply risks, they mention uncertainty in capacity, delivery time, manufacturing time, and costs. Wu et al. (2006) also classify risks according to the level of control that the company has over them, and whether they are internal or external to the company.

Hallikas (2003) presents studies made in two supply networks with an exploratory case study, in which in-depth interviews within the case companies were used (two OEM suppliers and several 1-tier suppliers). He classifies risks into demand, delivery performance, and cost management and pricing related issues.

As can be understood from above, the classifications vary from author to author. This study attempts to collect views from these various authors and put them under more general headings, which are called main constructs. They are the binding points, and attempt to represent the most suitable and relevant factors for supply risk classification. Consequently, they are the issues that also arise frequently in literature. The different classifications presented here are summarized in Table 2-5.

Table 2-5: Some of the different supply risk classifications in literature

Classification	Author
Profit impact vs. supply risk	Kraljic (1983)
Demand risk and supply risk	Johnson (2001)
1. Demand 2. Delivery performance 3. Cost management and pricing	Hallikas (2003)
Uncertainty in demand requirements and supply Risks that are either internal and, - controllable, - partially controllable, - or uncontrollable, or external and, - controllable, - partially controllable, - or uncontrollable	Wu et al. (2006)

As supply risks are specific to industries, proper identification will ensure full attention to all specific risks of the industry. That purpose is catered for in the third chapter with the practical application to telecom industry.

2.6 Assessment of risk probability and impact

Purchasing organizations need proactively assess the probability and impact of supply risk. Zsidisin et al. (2004) have explored, analyzed and derived common themes on supply risk assessment techniques. According to their findings, purchasing organizations can assess supply risk with techniques that address supplier quality issues, improve supplier processes, and reduce the likelihood of supply disruptions. The assessment methods range from informal to formal, as well as from qualitative to quantitative (Zsidisin et al., 2004). Steele and Court (1996) provide a conceptual approach, where they 1) classify supply risk probabilities ranging from low, medium, and high chance, 2) evaluate the likely duration of the problem based on past experience, 3) investigate the business impact with multi-functional teams.

According to Zsidisin et al. (2004) all prior supply risk assessments share common themes: they all consist of procedures to investigate the probability and impact of detrimental events that can occur with inbound supply. Yates and Stone (1992, in Zsidisin et al., 2000) note that a general process for risk assessment can involve establishing loss potential, identifying potential losses, understanding the likelihood of potential losses, assigning significance of losses, and appraising overall risk.

Companies conducting supply risk assessments either have stand-alone assessment processes, or they do the assessments as part of proactive supply management tools (Zsidisin et al., 2004). In an example they provide, a semi-conductor manufacturer used a ten-step procedure to assess risks:

1) Identify the materials/services to be assessed.
2) Identify the owner of the material/service who will be responsible for the risk assessment.
3) Start the risk assessment scorecard.
4) Review success criteria for each of the risk factors.
5) Collect data.
6) Determine risk level by comparing data to criteria on the risk assessment scorecard.
7) Conduct impact analysis.
8) Document risk level analysis and risk reduction plans.
9) Track progress.
10) Determine when to cease performing risk assessments.

The process measures eight critical factors, in order to have a reliable, predictable, cost effective supply of materials and services. The factors are

1) Design.
2) Cost.
3) Legal.
4) Availability.
5) Manufacturability.
6) Quality.
7) Supply base.
8) Environmental, health and safety impacts.

The manufacturer used commodity managers to identify these factors and their sub-factors, using scales from 1 to 5, with "1" being labelled "show stopper" and "5" as "qualified". (Zsidisin et al., 2004)

Zsidisin et al. (2004) also found out that there are several proactive supply management methods that simultaneously address supply risk assessments. These methods included supplier quality issues, supplier process improvement and the reduction of the likelihood of supply disruptions. Smeltzer and Siferd (1998) have come to the same conclusion by noting that "proactive purchasing management is risk management". In that sense, this study's topic could be also stated as "measuring/assessing/addressing supply capability" and not use risk terminology. Also Zsidisin et al. (2004) argue that supply risk assessment can be handled as part of proactive supply management.

Several studies attempt to measure supply risk with quantitative models. For example, Wu et al. (2006) utilize an analytical hierarchy processing (AHP) method with enhanced consistency to rank risk factor for suppliers and present a prototype computer implementation. Quantitative methods, however, use distinctly defined and measurable risk instruments and thus tend to narrow down the scope of possible risks.

After risk identification, an important part of the process is to assign significance to them. The assessment should include risk rankings, priorities, and likelihoods compounded by their impacts. These profiles can be associated with particular processes, relationships or strategies. This functions as the basis for risk management.

2.7 Inbound supply risk management

This section introduces some of the general approaches for managing supply risk. Why does risk need to be managed? This question should be answered in terms of marginal utility. What effort is put into risk minimization, mitigation, transferring, sharing, etc. should be weighed against an estimation of benefits. Sometimes corporations merely do not have the time or process in place. However, many risk management efforts work on a pool of risk sources: for example, building buffer stocks protects from shortage risks caused by both forecasting inaccuracy and low supplier capacity, but the extra stock does not reduce the likelihoods of these risks. This kind of reactive or passive risk management does nothing to tackle the root causes of unreliable supply.

How should risk be managed? Companies should manage risks holistically (Hallikas, 2003, 24) and appraise their overall risk position (Yates and Stone, 1992, in Zsidisin et al., 2000). In order to do so they need to establish loss potential, identify potential losses, and understand the likelihood of potential losses and assign significance to them, which is the normal risk management process.

There are various sources of supply risk, as presented in the previous section. Many risk management methods work for a pool of risk sources. According to Zsidisin et al. (2000) the two basic approaches are 1) process improvement [=risk minimization] and 2) buffer strategy. Process improvement includes e.g. supplier certification and quality management programs (Smeltzer and Siferd, 1998). The optimal risk management effort is probably found somewhere in between the two approaches, since the assessment of all existing risks is not possible (Yates and Stone, 1992, in Zsidisin et al, 2000). Buffer strategy means the inflation of inventory levels (so called safety stocks). It allows firms to guard against unprecedented risks, e.g. demand fluctuations or uncontrollable supply shortages. There are various inventory control methods, which are not discussed further in this text.

According to Tang (2006), it seems SCRM can be managed along two dimensions:

1. Supply chain risk management
    a. Operational risks: business-inherent risks, such as uncertain customer demand, uncertain supply, and uncertain cost
    b. Disruption risks: major disruptions caused by natural and man-made disasters such as earthquakes, floods, hurricanes, terrorist attacks, etc.
2. Mitigation approach
    a. Supply management
    b. Demand management
    c. Product management
    d. Information management

Tang (2006) has gone through an extensive amount of research papers and concludes the findings in four general approaches:

1. Supply risk: collaborate with upstream partners to ensure efficient supply of materials.
2. Product risk: collaborate with downstream partners.
3. Information risk: share data along the supply chain to increase predictability and visibility.
4. Demand risk: shape and modify demand uncertainty.

These are general approaches to managing the root causes of supply risk. When fulfilling its purpose, the company sources goods and services from upstream partners (supply risk), manages its own products to make them more conforming to manufacturability (product risk), shares information to be able to better respond to anomalies in its processes and environment (information risk), gets closer to its customers to attain more accurate knowledge of their requirements – what mixture of quantity, quality and timing of goods and services makes them satisfied customers (demand risk). The way Tang (2006) calls these issues may be slightly different of what is presented in this study later on. As understood from above, the general management methods are avoiding risk, reducing impact, transferring and spreading risk.

3 Inbound supply risk in telecom industry

This chapter analyzes the prevalent risks in the case industry by applying the concepts of chapter two into practice and utilizing findings from case company interviews to build the framework for the identification of operative risks. As supply risks are specific to industries, this chapter will highlight and eventually filter out supply risks that seem less relevant in telecom industry. For example: although seasonality in demand exists, it is lower as compared to consumer products, which have higher peaks e.g. during Christmas time. (Johnson, 2001)

This chapter emphasizes the limitations of the hub operating model in the assessment of its inbound supply risk. The effects and limitations of that are discussed in Section 3.1, where both the shortage risk event is described and how its impact is compounded by the order fulfilment procedure. Section 3.2 describes the case interviews and highlights the most significant lessons learned from them. Section 3.3 continues with further classification of the identified risk sources, concluding to a discussion of the apparent correlations between them.

3.1 Implications of the hub operating model

The case company is a global OEM supplier, specialized in providing telecommunication solutions to mobile network operators world-wide. It also provides installation services and consulting. The core competence of the company is the delivery of complete base station configurations at short lead times, close to the customers. The case company has arranged its logistics flows to go through a hub consolidation point, where the external suppliers deliver the goods (Figure 3-1 is a simplified imaginary representation). The hubs are located so that outbound deliveries would be as close to end customers as possible. Since the product portfolio is huge and constantly evolving, managing the supply base and inbound supply risk are critical to delivery capability.

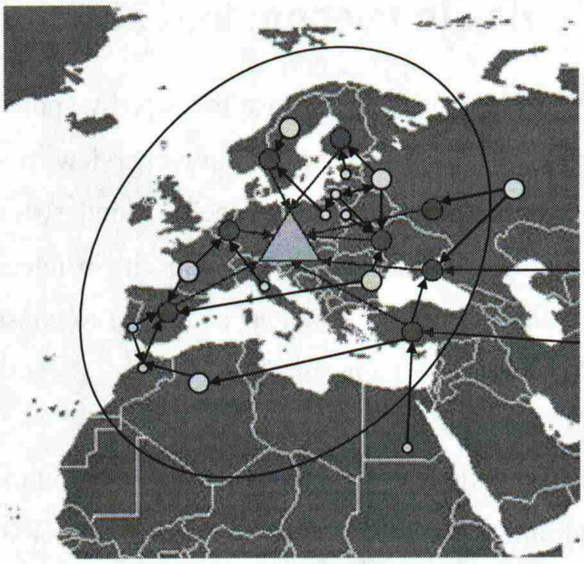

Figure 3-1: The hub concept geographically represented

The blue triangle in Figure 3-1 represents a fictional hub, where external 1-tier suppliers (green circles) deliver the purchased goods via road, air or sea freight (black arrows). The inbound supply from 2-tier suppliers (yellow circles) to the 1-tier suppliers is represented by the black arrows as well. As illustrated in the figure, suppliers can have business relationships of their own. The 1-tier base and its upstream network is in reality a very complex set of companies, especially if the dispersion of ownerships is considered. The shaded circle represents the area under which end customers are served from the hub. In simplification, if the customer is located outside the shaded area, it will be served from another hub, which is closer to it.

3.1.1 Shortage risk in hub operating model

According to Zsidisin (2002) inbound supply risk is "the potential occurrence of an incident associated with inbound supply from individual supplier failures or the supply market, resulting in the inability of the purchasing firm to meet customer demand and as involving the potential occurrence of events associated with inbound supply that can have significant detrimental effects on the purchasing firm."

In hub operating model, customers place orders to the hub. Typical order includes more than one line and possibly a complete product configuration of a full base station. The order cannot be delivered until the hub contains all of the requested items on the order configuration. For that reason, the impact of a supply failure is higher, and the probability of hub outbound supply failure occurring is higher than for an order containing only one item. A sales order configuration's dependency on individual items is represented graphically in Figure 3-2. The figure shows how a supply shortage of "item A" delays all configurations that contain it.

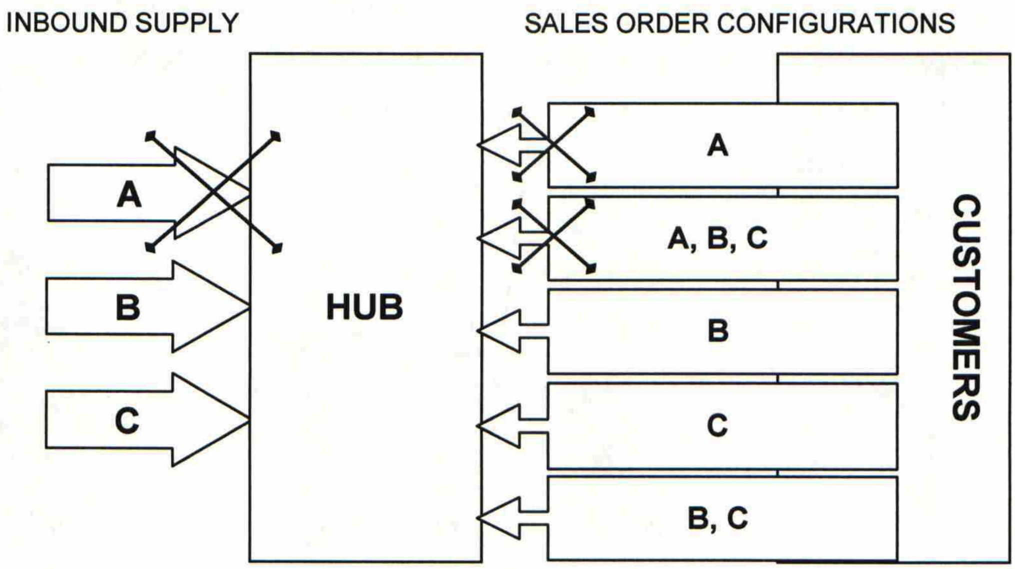

Figure 3-2: Creation of configuration delivery backlogs

Consider if "item A" (in Figure 3-2) is included in a configuration that holds hundreds of other items (not just B and C), with the total value at hundreds of thousands. Even if "item A" was individually thought of as a non-strategic B-item, it can quickly become the focus of high level managerial attention, as it affects high-impact deliveries. Partial deliveries of sales order configurations are not acceptable. This is problematic for many reasons and may incur hidden costs. Since the whole delivery depends on the availability of the whole configuration, then each individual item on the configuration will result in the same *risk impact*, if a shortage occurs. For that reason, risk management efforts should be spread equally over all of the items on that configuration. Consider an expensive key sales item (e.g. a base station cabinet) that has a very reliable supply and high capacity from several sources. This item is requested on the same configuration as a cheap bulk item, whose supply relies on a single source. Assuming a supply disruption occurs to the cheap item, it will render the supply capacity of the expensive item useless, because the configuration cannot be delivered anyway. Thus, by re-allocating capacity (or supply risk management efforts) to the cheap product, its supply risk decreases, and the overall delivery capability is improved.

Figure 3-2 emphasizes the fact, that impact-wise, the impact of inbound supply risk per item should be defined according to the combined impacts of all supply risks for the items on the same sales order configuration. However, it is not possible to know beforehand what kind of configurations will be ordered. Furthermore, first there has to be a method for assessing the impacts of single items. If that can be achieved, the risk levels can then be compounded afterwards by, for example, using historical data of average sales order configurations. The added value of risk assessment is to even out risk levels among different items – by process improvement or higher safety stocks. Thus, the aim is to ensure acceptable product availability at the lowest cost, by maintaining minimum reasonable inventory levels in the hubs – given the management targets of service level. The overall availability dictates the delivery capability of the OEM.

3.1.2 Impacts of actualized shortages

The impacts of supply shortages in hub operating model are listed in Table 3-1. These are based on findings from case company interviews and common sense.

Table 3-1: Impacts of supply shortages in hub operating model

Impacts of supply shortages	Description
Loss of customer and other stakeholder goodwill	Loss of future business Loss of credibility, damage to company image Loss of investor and other stakeholder goodwill
Delivery backlog	Capital interest cost Inventory storage cost and space consumption Loss of current sales (order cancellations) Indirect costs to the customer
Procurement expediting costs	Overtime production costs Expedited transportation

The most obvious impact of not being able to deliver a sales order is disappointing the customer and potentially causing them serious indirect expenses and losses. For example, a telecom operator might have already launched a marketing campaign, promising wireless coverage in areas where they end up not having it. Ultimately, bad delivery performance always risks future business by reducing customer loyalty, which can be an extremely costly impact. With modern global competition and the increasing number of OEM telecom equipment suppliers this factor is something that needs to be considered seriously.

In many cases, delivery backlogs caused by supply shortages incur inventory carrying cost, when large deliveries are pending due to missing items. They also tie up working capital, use up storage space and incur storage and handling costs. If the orders are delayed too much, there is a high risk of cancellation, which -besides the loss of revenues- leads to over-inflated inventory levels. Order cancellation risk exists for other reasons as well, but delivery delay is an important contributor to that probability.

Supply shortages also lead to non-standard purchasing processes, where procurement lead times are minimized wherever possible and expediting costs increase (e.g. supplier overtime production and the usage of air freight). The importance of the product should be gauged when assessing its potential impact on business. A useful starting point is categorizing products in terms of their profitability and demand volume or strategic importance into e.g. classes of A, B, and C products. That kind of classification is already in place in the case company.

3.2 Case interviews

3.2.1 Research methods and data collection

Several open discussions and six case interviews were conducted at one OEM telecom equipment supplier. Only one interview was possible to conduct at a key 1-tier supplier and thus the results of that section rely mostly on the literature survey. The interviews were made in order to increase industry specific knowledge and on general level to fill the gap in literature for item-level supply risk framework. The scope of interviewed companies might narrow down the possibility for generalization of the results, but the findings give rise to interesting future research topics, which are discussed in the concluding chapter (Chapter 4). The interview results show similar findings as discussed in the literature survey, and in addition, several findings that seem to be more closely related to telecommunications industry and the hub operating model.

Case study method is appropriate for new research areas where qualitative data is needed to create understanding of the studied phenomena. This approach provides a more holistic view on the topic and the emphasis is on interpretation of results (Stake, 1995 in Hallikas, 2003). A quantitative model requires carefully defined risk sharing instruments for the analysis and is basically a reductionist view on the matter as a whole.

3.2.2 Main findings

The discussions and interviews, mainly revolving around the OEM, gave rise to several conclusions. Firstly, it seems apparent that the fundamental causes propagating the risks of inbound supply failures are uncertainties in demand that reflect to supply through various ways. The givens in the short term also include product properties such as production lead time and global availability of production materials. Secondly, the factors that contribute to supply risk also seem to be highly correlated with each other. For example, high financial risk (e.g. liquidity problems, unhealthy capital structure, etc.) affects risk taking incentives, which in turn increases uncertainty of supply. In addition, the overall risk position of any given company affects every company that deals in business relationships with it. In other words, company-level risks in a supply chain are related to each other, as also concluded by e.g. Hallikas (2003). If the OEM has a risky supplier, the OEM's overall risk position is relatively higher. The identification includes also risks from external sources that all the players face simultaneously, and reacting in potentially different ways. These are related to the operating environment and business environment. An interesting proposition by the interviews was that the risk imbalances between the parties would tend to shift back and forth the supply chain through time. All these findings lead to the conclusion that risk assessment on general level is a very broad subject of study. Eventually, the interviews gave rise to some general themes that can be summed up as:

1. product substitutability: how many sources there are and how compatible the products are in reality,
2. demand characteristics: number of customers and variance of customers,
3. supply characteristics: number of suppliers and variance of suppliers and supply base,
4. bureaucratic challenges: complexity of requirements and number of separate material flows,
5. basic purchasing components: lead time, inventory value, capacity and flexibility.

After careful consideration of the best ways to categorize risks, it became obvious that none of these risk contributing factors cause supply shortages per se, but just add to the likelihood of that happening. For that reason, it is not possible to come up with a numerical risk value for overall risk probability of a supply shortage per material per given time period. It also began to look like supply risk should be assessed on item-level, because that allows taking into account the complete process the product goes through the supply chain. Starting with product related risks, all external risks can be thought of as internal to product risks. For example, a certain product's risk level is either reduced or increased by risks pertaining to its supplier; a risky product supplied by a low-risk supplier has a lower overall risk level than a risky product supplied by a normal or high risk supplier. A risk assessment is meant to direct attention to such root causes of inadequate processes or procedures that might otherwise result in worse performance than what would be actually possible. These factors include also more complex phenomena that are related to human behaviour; specifically the behaviour of decision-makers who face the question of what is the optimal course of actions to maximize profits with minimal risk in the long term, without damaging business relationships. The interviewees had interesting comments on this issue. They are discussed in several instances where the risks related to the OEM-supplier relationship are discussed.

One finding was that the higher the risk for a certain product, the longer the lead time to provide it to the end customer. The product's risk level is augmented by customer specific requirements, i.e. the small size and/or the heterogeneity of the customer base. These are risks that in effect also become supply specific – having high purchase risks for each company in that supply path. With high risk emerges risk aversion, which practically means long lead times if products are made against orders.

Some topics that were found in the literature survey were considered less important by the interviewees. One of these was price escalation risk, which was described as the opportunistic price setting behaviour by a sole source supplier (Hallikas, 2002). Price risk's impact on supply risk was thought only to cause delays in purchase order confirmations – in the case of an open price negotiation. Normal assumption of continuing business and the existence of a purchase agreement were thought to ensure that prices would not cause shortages, unless there was an insurmountable disagreement between the parties.

The actual impacts of supply shortages were also discussed. For simplicity, in the classification in the following sections, it is assumed that the risk impact only depends on the assessed product's business impact after a supply shortage, and thus the impact would not be dependent on the risk sources. Thus, the concept of impact is simplified and risk management justification is decided upon after the risk assessment.

Another issue that emerged in the interviews was that the OEM can cause outbound supply risks internally. To put it another way, the impact is exactly the same as the actualized inbound supply risk – i.e. an outbound supply shortage. Internal supply risks result from rigid processes, lack of information sharing and visibility to the overall optimal solutions, etc. These can result in the incapability to fulfil customer demand. The reasons for lack of internal information sharing was though to be a result of the hierarchical structure of the corporation, where individuals work in very specialized silos of tasks and responsibilities. These findings were discussed, but they are not included in the risk framework, because the topic of this research is on external risks.

3.3 Supply risk framework in telecom industry

This section discusses the interview findings in more detail. They are again grouped into 1) risks related to suppliers, 2) risks faced by 1-tier suppliers (such that increase the risk faced by the OEM), and 3) risks related to the product. Risks seem to have high levels of correlations. If a certain risk factor is estimated high, co-affected risks can be checked from the risk correlation matrix (Figure 3-4, pp. 66). The risk event evaluation is eventually done on product-level, as illustrated in Figure 3-3. To the supply risk level of an individual product contributes the riskiness of that particular supplier (3.3.1 Risks related to suppliers) and the product's own characteristics (3.3.3 Risks related or assigned to products). Furthermore, the overall riskiness of an individual supplier is correlated with its implicit issues like financial stability, and explicit issues like its relationship with the OEM. Risk correlations inside these factors also affect each other; if a certain risk source is elevated, it can make other risks more likely, which reflects the endogenous nature of risks.

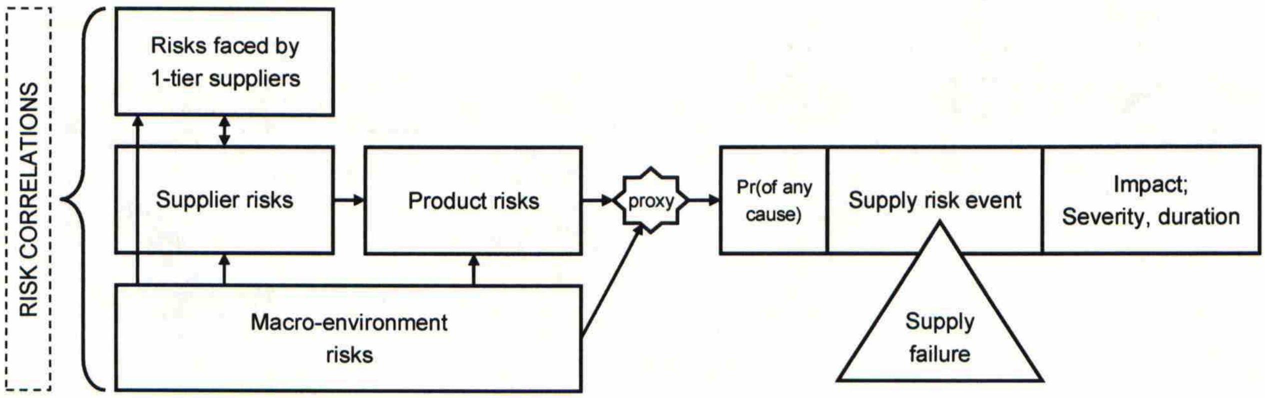

Figure 3-3: Product level supply risk evaluation

Finally, the individual product's estimated risk level is multiplied by its potential impact on business, if a shortage occurs. If possible, the shortage recovery time (duration of risk event) should be estimated as well. In the assessment phase, these considerations give rise to prioritization: the higher the probability (risk correlations taken into account), the higher the impact, the longer the duration and the more the OEM has control over the issue – the more important that risk is to eliminate immediately. If it cannot be eliminated, higher safety stock levels need to be accepted. There are also external risks in the macro environment that are common to all parties, especially in the same industry. These are the types of risks not considered further in this study, since the focus is on inbound supply – specifically caused by inefficiencies in the supply base and its coordination.

3.3.1 Risks related to suppliers

This section discusses all risks that can be aggregately defined as specific to individual suppliers. They are listed in Table 3-2 and discussed in detail in the following paragraphs.

Table 3-2: Risks related to suppliers

Type of risk	Description	Causes and/or effects
Supply base	Complexity	Geographic dispersion; amount of bottle-neck materials, (Choi and Krause, 2006): Number of suppliers; degree of differentiation; level of inter-relationships
	Management (explicit risks)	Control; flexibility
	Sub-supplier risks – *supplier risk multiplier*	Implicit risks of the sub-suppliers
Capacity and flexibility	Overall capacity and slack	Potential to cope with demand volume (capacity); demand changes (flexibility)
	Customer (OEM) prioritization	Customer profitability
	Competence of production planning	Optimal use of production capacity
Power structures of the relationship	Dependence on the supplier	Percentage of purchases; percentage of single sourced products
	Supplier dependence on the OEM	Percentage of sales; percentage of product specific customers
Risk taking incentives	Risk profile	Goal alignment, mutuality of vision, prospects of business growth, value addition by the supplier, common history together, risk management capability
	Other issues	Liability policies set by management, asset specificity, financial risk
Existence of key competences	Product management	R&D, design, quality, technological change
	Planning, purchasing, sourcing, logistics & operations	Operative capability
	Technology adaptation and transfer	Product and production technology competitiveness
Person risks	Competence reliance on few people	Risks of competence loss
	Decision-making	Ability to make quick decisions, locality of decision-making authority
Visibility of operations	Information sharing, willingness to cooperate, openness, trust	History together, fairness of risk sharing
Quality	Products and production	Conformance to specifications, maintained quality of production equipment; quality at all stages: design and volume production
	Processes and competences	Quality of processes, quality or competence of key functions (logistics, finance, operations, etc.)
	Quality principles	Existence of quality ideology; continuous improvement
Financial stability	Over-optimization, minimal inventories, zero risk taking	Uncertain supply, long lead times, high purchase risk

Supply base

Supply base category includes all issues related to the upstream network of the particular 1-tier supplier. A common theme was the notion of poor visibility to the upstream (Interview D) or low commitment, which manifests itself as low responsiveness and information sharing, low risk taking initiative, and unreliable supply schedules and quantities. The more outsourced and complex (Choi and Krause, 2006) the upstream supply base is and the less the supplier is able to manage it (Interview C), the higher the risks from sourcing. That is because a supplier's risk management capability directly dictates the way it can take risks (Interview C). If risk taking is done blindfolded, the results are random. If risk taking is deliberate and based on analysis, experience and shared efforts in the supply chain, mutual benefits should realize. Since risks are interdependent, also risk management should be a concerted and openly discussed effort in supply chains. For more discussion on risk management, see section 2.7 in literature survey.

The supply base risks are compounded if the supplier does not have proper key competencies in place: MRP management, purchasing and supply base management (Interview C). Unreliable feed of production resources results in challenging production planning and scheduling – and consequently unreliable order confirmations to the OEM. An important issue is how much control the supplier has over its supply base. If the sub-suppliers do not share information openly, have low incentives in risk taking and maintain minimal inventory levels, the flexibility of supply from upstream is low. When high variations in end demand occur, the supply network is unable to react quickly. Eventually, the implicit risk level of a particular supplier (from OEM perspective), depends on the sum of the risks of all of its sub-supplier's risks. This reflects the fact that each company faces risks both from downstream and upstream and the sources are quite similar at all stages. The supply chain's risks are thus interrelated, as concluded also by e.g. Hallikas (2003, 21).

Capacity and flexibility

The overall capacity of the supplier depends on its available equipment and labour force, and how quickly these can be ramped up (or down). The time span where capacity is fixed depends on the industry and the type of production in question. According to Interview D, some product families may be quicker to ramp up than others, if for example, the supply consists of labour intensive instead of capital intensive processes, because of long lead times in procuring new equipment. A supplier's capacity and flexibility are also highly dependent on power structures in the relationship and the supplier's financial situation (e.g. Interviews B, C, and D). It was thus widely agreed that the financial stability affects –among many other factors– also capacity (be it equipment, investments, or labour). If the supplier's financial situation is unstable it may provide bad customer service and it may prefer short-term profits (Interview B). It is a notable fact that a supplier's production planning capability is a strong determinant of its optimal capacity usage (Interview C). A less acknowledged fact is that personal chemistry of contact interfaces might also affect customer prioritization (Interview B).

More likely, customer prioritization comes up with the fact that the supplier's capacity may be shared with several customers. It would be important for the OEM to estimate the extent of shared capacity, as also concluded by Zsidisin et al. (2000). The capacity (and slack flexibility) that is dedicated to a single customer depends mainly on the supplier's willingness to prioritize that customer, which further depends on the customer's profitability or expected life-time profitability. According to Interview B, a customer's profitability is directly correlated with the level of negotiated purchase prices, purchase volume, stability and expected duration of the relationship. For example, even a lower sales margin is attractive, if the volume is high and the expected duration of the relationship is long. This may be one of the reasons that make large buying companies able to leverage their market power and achieve low prices. Anyway, it is crucial for the OEM to stop and rethink whether it is a profitable customer to the 1-tier supplier, since that has a direct correlation with the level of customer prioritization. If the focus is on delivery excellence instead of robust cost efficiency, the ideology should be such that the better off the supplier is, the better off the OEM is. Besides pushing down the prices, the OEM should treat its suppliers like its own customers, or even better.

Power structures of the relationship

According to the interviews, the relative power of the players in a relationship is an important aspect that is interrelated with everything. Risk sharing balance between the parties affects supply risk: if risk taking is off the balance, supply risks become prevalent. It is a typical accusation that large OEMs push a heavy load of the risks to suppliers, partially acknowledged even by the OEM itself.

Risk sharing is correlated with power structures and the bargaining power of each partner. Especially in the longer term, risks are correlated with the level of dependence on the other party. If the OEM is highly reliant on the supplier, several types of risks can occur: the supplier can behave opportunistically by pushing up prices if it realizes that is has greater bargaining power (short-sighted strategy). Typically, high dependence results from the supplier being the single source for a material (Interview B). Furthermore, several other risks can escalate when the OEM becomes dependent on a financially struggling supplier.

A supplier's high dependence on the OEM can also increase the OEM's inbound supply risk. If the supplier has an unhealthy customer portfolio, its demand risks become unbearable. If its business depends on the OEM's large purchase volume, a sudden low period can eat out its performance – resulting in higher supply risks. The main measure of seller-buyer dependence is the fraction of revenues that each one represents: the supplier's percentage of sales as a fraction of the buyer's percentage of purchases. Whether the buyer's total purchases are measured as fractions of total turnover, or product category turnover, is up to the risk analyst to decide.

Supplier's risk taking incentives (risk profile)

According to e.g. Interview A, a significant feature of OEM's supply risk derives from the supplier's risk taking incentives. Risks faced by the supplier affect the risk experienced by the OEM. According to the interviews, the factors that make up the supplier's risk taking incentives are e.g.:

- mutuality of common goals and vision,
- prospects of business growth,
- value addition by the supplier,
- liability policies set by management,
- asset specificity,
- financial risk, (Interview A)
- common history together (Interviews B and C),
- and the supplier's risk management capability (Interview C).

Finally, the long term strategic relationship will affect short term risk taking (Interview A). If these root causes do not give reason to take risks, the probability of supply failures increases. When the partnership is strategic and goals are aligned (both partners serve the same end customer need), then the fair sharing of profits is in the best interest of both parties in the long term and risk taking incentives are high. High goal alignment correlates with the deeper level of cooperation and the requirement of the suppliers to commit to higher risk taking. If the supplier has reason to expect growing mutual business, it is able to commit to higher risks and liabilities by the assumption that these pay off; the supplier can invest in specific technologies and production capacity, make advance purchases against the forecast, and reserve slack capacity for production. However, liabilities can be limited by the ruling of management or Board of Directors. According to Interview A, the value addition of the supplier is connected with its risk taking. If the supplier is predominantly a low value adder, it will have less dependency on the process and thus less incentive in risk taking. This may be the case with contract manufacturers: if the OEM creates the product design, chooses sub-suppliers, defines the liabilities and dictates the production to one of its contract manufacturers, a valid question is 'what is in the interest of the contract manufacturer to take risks?'

Asset specificity is manifested mostly in demand risks, which is a risk that each step in the supply chain faces, but with different nuances. As regards risks of demand changes and asset specificity of production technology, the supplier faces volume and design risks. Design risk is higher if the product is an OEM design. Consequently, the higher the design risk, the higher the volume risk, since the volume is tied to one design and one customer only. Supplier's own design is standard to its own portfolio and can be sold to more customers thus reducing excess risks. Asset specificity is dominantly related to risks related to products (see Section 3.3.3) or specificity of production equipment.

The common history of the parties affects supply risk (Interview B). The OEM and its suppliers experience unique development paths in their relationships and everything that takes place during the relationship can affect supply risk. A supplier's risk taking incentives are dynamic and may change over time (e.g. Interviews B and E). A typical example of a set-back that reduces supplier's risk taking is the case when the OEM forecasts high demand and acknowledges zero liability when none of it actualizes. Later on, that kind of experiences may be used as excuses for bad performance by the suppliers (Interview B). Visibility of operations and information sharing are stated as crucial factors of successful cooperation in many instances in literature as well as in the interviews. The supplier's willingness to cooperate is dependent, like its risk taking incentives, on the root causes of why the parties have entered the business relationship in the first place, and the common history accumulated during the relationship.

Technology and product management

This category requires an ambiguation: technological change as part of demand risk is discussed in section 3.3.3 (Risks related or assigned to products), where changes in technology drive changes in customer requirements, reflected in the final products (asset specificity and design risk). This category, as a risk that is aggregately applicable to individual suppliers, discusses technology as the competitiveness of the supplier's production equipment and R&D: the ability to maintain state-of-the-art equipment and technological flexibility with minimal obsolete risk.

A supplier's product management is one of the most important competences. New product development, product quality and lead time from design to market can have significant effects on operative supply risks. If product development is incompetent, supply risks are predominant especially in cases where an old product technology is ramped down and a new one ramped up. According to interview C, technology transfer is always a challenge for operations. Practically, technology transfer means certain degree of copying existing technological knowledge: opening a new manufacturing site, expanding a production line, etc. The more there are uncertainties involved, the longer it can be expected to take. Suppliers often seem to overlook the challenges in technology transfer (Interview C). When there is an issue with capacity, it may be suggested that it is surmounted with technology transfer. It appears that the lead times in doing so are sometimes estimated over-optimistically. The supplier might have ignored learning curve effect, or may overlook the challenges of launching a production site abroad in another culture. Even in the case of a 'simple' line expansion, it takes a long time to recruit new personnel and train them – unless over-time labour is used with existing personnel.

Existence of key competences and person risks

Knowledge and competence management are important for any company's performance. In the interviews, certain functional competencies were found to be more important aspects than others, as regards supply risk. Unsurprisingly; operative, technological, and logistical competences were emphasized (Interviews B and C). Marketing as a function might increase supply risk, if its communication with manufacturing is not working. Operative competences include MRP management, production planning, purchasing, order handling, warehouse management. An example of bad planning was demonstrated by a supplier who bought components from China for assembly in Europe. The components were the bottle-neck parts for the assembly line's capacity – and the final product needed urgently in a customer project. The components were low in weight, but they were ocean freighted without consulting the buyer at all, even though the freight would have been the buyer's responsibility (Interview B). A logistically incompetent supplier would have no visibility in its own operations: the quantities of in-transit goods, version control, uncertainty in inventory levels, etc. A supplier should have a clear idea of its supply capability at each moment, in the form of a reliable and plausible production plan.

Person risks can occur when key competences are relied upon a few invaluable individuals in the personnel with irreplaceable work experience. In the longer term, competence risks are inversely correlated with the size of the corporation (the bigger the company, the lower the competence risk). In the short term, changes especially in customer-dedicated teams can have great effects on the performance. The loss of personnel competence can realize through many ways, e.g. corporate take-overs or mergers, when key personnel might be tempted with better offers or departure packages to leave the company. It is difficult to assess how much competence is at stake at each time by potential takeovers, but that risk does exist. In one case (Interview B), a key supplier to the OEM was taken over by an overseas company. The acquiring company streamlined the supplier, laying off a large portion of key personnel – resulting in brain-drain in R&D, product management and logistics – making the new company practically a sinking ship ever since. This evidently resulted in very uncertain supply schedules, quantities, and overall bad planning from the supplier. That quickly cost it its position on the list of preferred suppliers. To utilize this example fully, it is noteworthy, that the same merged company became financially unstable and the risks related to the relationship became unsustainable including financial arrangements ranging from direct purchases of obsolete stock (i.e. a legal form of subsidizing), and 100 % risk purchases, because no production started unless with firm orders from the OEM. The situation forced sourcing to phase out the supplier and ramp up a new one as quickly as possible[3].

Competence can be deemed as insufficient if it depends on one individual only, or does not exist at all. According to Interview B, some suppliers do not understand the importance of having operative

[3] Although, at that point it became difficult to ramp up a new supplier with a promise of a very low forecasted demand, since almost all the customers had switched to the second/alternative source supplier already (i.e. the original split of 50-50 had become 95-5, leaving 5 percent of forecasted demand for the ramp-up.)

and logistical competence. These companies tend to emphasize sales functions and assume that the products are so good that they sell themselves. No product becomes sold before it is labelled, registered, picked, packed, booked for shipping, shipped, received, etc. – taking into account legislation and document requirements.

According to Interview C, an important point related to suppliers' competence is localized decision-making authority and the ability to reach conclusions quickly. It is also a culture related issue – some cultures or companies need more time and several meetings to make big decisions, which may take two seconds in others. If the decision-making authority is hierarchical, i.e. the operative functions need approval from higher levels, the decision-making lead time is longer. It can be further augmented by time zone differences: e.g. a Chinese manufacturer that is headquartered in the US.

Financial stability

Financial stability is a root cause of many operative problems (e.g. Interviews B, C and D). Supply risks emerge, if finance is unstable or in bad condition, or in the extreme case in a liquidity crisis, where production starts only against a firm order. In telecom industry, make-to-order production would in many cases result in unacceptably long lead times. The level of uncertainty is directly correlated with the severity of financial problems: if the supplier cannot take any risks, the direct effect is a tactical shift to cost efficiency instead of high performance. Unsustainable over-optimization results in zero inventory investment, unreliable supply schedules and quantities. Needless to say, supply chains (or suppliers) focused too much on cost-efficiency, become fragile to disruptions. If end customers are not convinced by the supply base's performance, it will lose business to competitors. The situation worsens when investors lose confidence and begin to withdraw funding.

Financial risk is one of the main determinants of a supplier's risk taking incentives. It shapes the supplier's capability to finance its operations and develop new products and technologies (Interview A). It affects also almost all other types of risks (Table 3-2). Financial performance should be monitored regularly, and alarming indicators should be reacted upon quickly. Problems tend to deepen if a badly performing supplier is maintained too long. It may become challenging to give up a supplier at a later stage. In the case company, required financial business intelligence can be obtained at request from the department of Corporate Finance and Control.

3.3.2 Risks faced by 1-tier suppliers

As illustrated in the framework in Figure 3-3, on page 44, these risks are assessed from OEM perspective: what risks do 1-tier suppliers face that increase their outbound supply risk. These risk categories are based on the OEM interviews and one 1-tier supplier interview. For theoretical saturation and higher validity, more interviews to the 1-tier supplier would be needed. Literature survey findings are thus emphasized (refer to Table 2-2 on page 22). However, these findings definitely have truths behind them and at least indicate to some potential risks. The findings in this section are categorized in Table 3-3 and discussed further in the following paragraphs.

Table 3-3: Risks faced by 1-tier suppliers (case interviews)

Type of risk	Description	Effects
Supply failures and impact	Inbound and outbound	Loss of business, difficulties in resource planning, lower quality
Macro environments	Operative, business, regulatory, political	Cultural issues, bureaucracy regulations, legislations, unpredictable instabilities
Demand risks	Upstream and downstream	Inconsistent consumption, shortage risks, excess risks, lower risk taking incentives
Sourcing	Global availability	Materials, skilled labour
	Off-shoring	Transportation damage, lead time
	Relationship	Sub-supplier terms and conditions, risk taking incentives
Technology	Specific investments; long development times	Technology failures, opportunity costs

Supply failures and impact

The impacts of outbound supply failure carries a significant risk of losing business to competitors, which was seen an utmost important issue (Interview E). Risks were considered affordable if they helped secure businesses. The impacts of sub-suppliers failing to deliver, i.e. inbound supply failures, were thought to cause difficulties in production planning, workforce utilization and eventually leading to reduction in product quality. Production planning becomes difficult if parts of production resources are replenished with unreliable schedules and quantities, because planning is based on capacity reservations of both equipment and labour – i.e. workforce utilization. The reduction in quality would be the result of having to come up with backup materials of potentially lower quality for production, or the completion of the production process in non-standard steps.

The operative/business, regulatory and political environments

The operative or business environment, the regulatory and the political environments were felt risky and such that increase uncertainty in supply. E.g. European holiday periods coupled with demand fluctuations were thought quite challenging to cope with, if factories remain shut down for several weeks. As for the regulatory environment, new legislation was mentioned to have various impacts on operations: e.g. the recent EU directive of RoHS-compliance[4] resulted in two separate flows of inventories to be managed for some products. Related to that, WEEE[5] legislation increased logistical burden on all companies now that they have to manage waste more efficiently. The aim is to get rid of all non-recyclable materials. Political risk was thought to have un-expectable results: in one example, the government forcibly shut down both factories of a circuit breaker supplier, resulting in lengthy backlogs and affecting several final products.

Demand risks

Demand risks were considered in terms of both risks related to downstream and upstream partners. Regarding upstream, the consumption from sub-suppliers was mentioned to increase risk, if the consumption was inconsistent. That would increase inventory fluctuations at each tier level, increasing a shortage risk in sharp demand rises, and excess risk when forecasted demand is not

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[4] The directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment 2002/95/EC (commonly referred to as the Restriction of Hazardous Substances Directive or RoHS) was adopted in February 2003 by the European Union. The RoHS directive took effect on 1 July 2006.

[5] 2002/96/EC: the collection, recycling and recovery targets for electrical goods. Part of a legislative initiative to solve the problem of huge amounts of toxic electronic waste.

consumed. Exceeded forecasts in turn will affect sub-suppliers' risk taking incentives: sub-suppliers quickly become suspicious of any future forecasts. If products are relied on as single sources, supply risks are much more prevalent and all demand risks become exacerbated. The supplier's risk taking incentives further depend on the size of the opportunity that it is facing. More risks can be taken in order to secure business. The interview discussed several example cases, where sub-supplier's risk avoidance had lead to direct loss of sales with the 1-tier supplier. Risk avoidance reduces inventory carrying cost, but is more likely to result in backlogs and long lead times. In the longer term, risk taking behaviour was believed to shift along the supply chain in wavy motions.

Sourcing

Risks related to supply sourcing include transportation risk in off-shoring, i.e. sourcing from faraway low cost countries. The global availability of certain production resources: materials, components, skilled labour, etc. is sometimes very scarce. E.g. the availability of skilled labour in many emerging markets is non-existent. The market price fluctuations of raw materials like lead and copper have significant effects on product costs and availability. The market price is driven by the balance of global supply and the availability for many items has become more risky after the Great Telecoms crash in 2000, which resulted in several bankruptcies in telecom equipment supplier manufacturers, drastic reduction in the supplier base, and increasing market prices when global demand began to exceed global supply. That is an example of an uncontrollable external reason that forces increasing focus on cost efficiency and reducing risk taking significantly. For example, the interviewed 1-tier supplier went through nearly an 80 percent reduction in sales revenues in only six months and suffered credit losses.

The relationship between the 1-tier supplier and its sub-suppliers was found to be a risk increasing factor. The uncertainty in inbound supply was thought to increase if sub-supplier terms and conditions were not met: e.g. payments were delayed outside the agreed period. Other more miscellaneous factors increasing risks were mentioned too: high level of hierarchical structure in corporations, low level of operative employee empowerment, non-locality of decision-making and demand information distortion. Demand information might become distorted if individuals make adjustments in the process: a customer forecasts, the sales person inflates it, the planner deflates it and finally a manager makes further adjustments based on her experience.

Technology

Technological aspects can affect supply chain operations. If specific investments are made to R&D projects, and the technology does not meet project requirements, plenty of time may be invested without commercial returns. The long development time was considered risky as regards time-to-market competitiveness. For example, a project designing a new innovative product employed about 3 to 4 full-time designers for 18 months, with no sales revenues so far. If the product was not transferred to volume deliveries soon it was feared that competitors would come up with alternative technologies. R&D has uncertainties that can affect operations: approvals on technology may take time. An interesting case is the parallel development of technology projects with the same eventual merging point (components and finished goods). If any of the parallel development paths fail, the whole conjoint project might get cancelled.

3.3.3 Risks related or assigned to products

The idea of categorizing certain types of supply risks under this heading is to present the fact that supply risk seems to be foremost related to individual products' supply and demand uncertainties. This view was presented also by e.g. Johnson (2001) and Wu et al. (2006). In addition to enriching these categories, it was found that product characteristics also amplify some supply risks. All the aspects under these categories are broken down to a couple of sub-factors, which listed in Table 3-4, and discussed in detail in the following paragraphs.

Table 3-4: Risks related or assigned to products (case interviews)

Type of risks	Proxies	Description/contents
Supply uncertainty	No. of supply sources	Multiple-, dual-, or single sourcing Substitutability
	Supplier risk, multiplies product risk	See Table 3-2 on page 45
	Procurement lead time: average and variance	Production lead time / fill rate Transportation lead time (sourcing channel)
	Quality conformance	Supplier propensity to produce quality
	Excess purchase risk / OEM buyer risk aversion	Low inventory rotation Obsolete inventory due to demand stop The unwillingness to take inventory risks
Demand uncertainty	Distribution (volume and variance), changes over time, abrupt changes	Customer base variance, size, heterogeneity
	Changes in demand requirements	Technological change
	Substitutability of demanded product	Specificity in product supply and/or demand
	Forecast accuracy	Inaccurate forecast increases risks of shortage and excess
Product characteristics	Value (and value addition)	The base cost of the product The distribution of value addition by each tier
	Weight and volume	Unit weight and volume per package
	Obsolescence risk	The expiration of the product due to ageing or e.g. changing technology
	Technical complexity	The amount and technical novelty of parts

Supply uncertainty

Supply uncertainty is propagated in many ways on item-level. First of all, the number of supply sources (single-, dual-, or multiple) for each product is the most relevant measure of its risk level. Then the implicit risks of each supplier will affect the supply risk level of that particular supplied product. The OEM's target is at least dual sourcing for each item type. The degree of similarity can vary: the items can have the same code or only the same functionality, being members of different product families that cannot be mixed, i.e. being non-compatible. The substitutability would therefore rely on similar functionality. High product substitutability enables flexible fulfilment of customer demand. However, according to Interview C, there are several restrictive factors to this. For example, a customer may not be able to switch to another supplier's product, because it is used to the existing product's properties. These switch-over costs consist of inconvenience costs: the customer has to relearn the installation procedures and it may already have created a preference for the existing product in other aspects as well. And as mentioned above, compatibility may be an issue, especially in the case of upgrades.

The procurement lead time is one of the main components of purchasing management. The longer the procurement lead time and the greater the variability, the more challenging it is to respond to demand fluctuations. In this study, the procurement lead time is defined as to consist of the elapsed time between the moment the buyer sends a purchase order, to until the goods are received to stock. In that sense, the procurement lead time ($L_{procurement}$) consists of the actual production or supplier sourcing ($L_{production\ or\ sourcing}$) or fill rate (demand served directly from stock). The fill rate changes dynamically, and it depends on what the supplier carries on stock at each moment. That may depend on how much has been agreed as the supplier's consignment inventory. The supplier may also have accumulated its inventory levels based on a forecast from the OEM. The transportation lead time ($L_{transport}$) depends on the geographical separation between the supply and demand. The variances of all components (V_{all}) increase the unpredictability of the procurement lead time. Unpredictability is a factor that brings a high level of incremental uncertainty to supply, since it makes supply planning more difficult. The dispatch and receipt lead times are not significant, except in case of non-conforming quality or underperforming warehousing operations.

$$L_{procurement} = L_{production\ or\ sourcing} \text{ or Fill rate} + L_{transport} \ (+ L_{dispacth\ and\ receipt}) + V_{all}$$

The differences in these factors need to be reviewed in terms of opportunity costs: e.g. low cost sourcing from China may provide unit cost savings, but the long transportation lead time increases procurement lead time and thus the challenges in supply management. A cost saving is easy to measure, but the opportunity costs of outbound supply risk are very vague and difficult to measure and as the result, it is hard to compare these two cost categories in order to justify higher unit costs in favour of better supply capability. For that particular reason it is usually completely ignored. The sourcing channel of each product determines the transportation lead time. Indeed, an individual supplier can have different sourcing channels for different items – hence the requirement to look at risk on item-level instead of only aggregately on supplier-level. The sourcing channel is dictated by the sourcing choice: where the supplier is geographically located. The location might not be the most optimal or preferrable, but can be constrained by e.g. labour availability (Interview E). The transportation lead time naturally depends on the separation between demand and supply (e.g. Johnson, 2001), and the transportation mode. The modality is restricted by weight and volume of the product: the heavier and more volumous the product is, the less likely it can be shipped via air (and the more it costs to stock and handle). Sea freight increases both inflexibility of the supply schedule and the lead time variability. The total variability of the procurement lead time is the sum of the variabilities of its components.

The risk caused by the procurement lead time should be assessed in conjunction with demand uncertainty of that particular product. A long-pipeline product supply (e.g. a typical example for sourcing from China) with level-changes in demand inevitably cause lengthy periods of both shortage and excess. Couple the issue with long production lead time and the delivery capability becomes unsustainably low. Properties of demand uncertainty are discussed later in this section.

> High reliance on Chinese production is very typical to any industry these days. According to Interview B, the original reasons that have attracted companies to China have started to diminish. Labour rates and material costs are increasing and IPR (Intellectual Property Rights) are at risk. The political risks are felt to be significant, and the internal market growth is substantial – China may soon not need external markets for growth and unsustainable legislation exerted towards multinational exporters would not be unexpected.
>
> Besides the facts of demand-supply separation and logistical inefficiency, the Chinese production is often found to have very low yields and poor quality (Interview B). Logistics costs are also increasing as fuel prices have gone up and ocean freight costs are catching up. Furthermore, ocean freight is not as green a mode of transportation as before. Environmental issues, all in all, are becoming very important to global supply chains.

The OEM's willingness to manage risk by stocking more of the item depends on the product characteristics. The more valuable the item is, the heavier the burden on capital costs like inventory carrying charge. This category includes the risk of excess purchasing, which in turn increases supply risk: risk averse purchasing will not drive supplier production and can thus lead to supply risk that could have been avoided. The avoidance of excess purchasing makes financial sense and is in that way an internal risk to the OEM, caused by the product characteristics. The risk of time-based obsolescence increases the OEM buyer's risk aversion: for example industrial batteries, which are in addition very valuable. Theft is a risk in some countries, but as it is not an operative risk it is left out of the model.

The procurement lead time in terms of supplier's procurement lead time depends on similar issues throughout the upstream supply base, but from OEM perspective it may be best assessed in terms of the product's sourcing composition and technical complexity. If the product consists of an unreliable supply of raw materials, components, or expertise labour (Interviews C, E), i.e. the more complex the product is, the more likely it is that from time to time the availability of any of the sub-assemblies is compromised. Usually the visibility to the upstream network is very low, noted also by a 1-tier supplier (Interview E). This was seen a very significant source of supply risk. The overage complexity of the supply base has been concluded to increase supply risk also by e.g. Choi and Krause (2006). As stated in the formula of the overall procurement lead time, it depends also on both the supplier's or supply base's capacity and inventory levels. These are driven by the purchasing behaviours and risk taking incentives at each tier level throughout the supply chain. After all, these incentives are such that either glue the companies together to achieve common goals, or make them risk averse opportunists – or something in between.

The variability of the procurement lead time is increased by quality issues. Product quality was considered from three different perspectives: R&D, product management, and logistics. If logistics quality is bad and errors in shipments are noticed only at receipt, unexpected delays of unknown length incur. These can have rippling effects especially in upstream production. In case of final products and no value addition by the OEM, a delay during receipt can easily result in a bad track record of on-time outbound delivery accuracy if the customer order is closely matched with the receipt. A new supplier is always a high risk in terms of quality, because it is not possible to know its propensity to produce good quality or exhibit logistical quality, before some experience is accumulated. However, a supplier can be trained for better quality performance. Quality problems in R&D and design if new product launches have defects or unmet requirements by the OEM, can increase costs and cause long delays as was also discussed in Section 3.3.2 (Risks faced by 1-tier suppliers).

Demand uncertainty

The uncertainty caused by fluctuations in customer demand is a root cause of operative instability. The demand distribution of the product should be studied in detail and compared to the original forecast to gain also an analytical appreciation of the forecast accuracy and other properties of demand per each product. The risks that demand uncertainty poses to the supply network seem to create a dynamic web of reactions.

The changes in demand have short and long term effects throughout the supply chain. Its average volume and variance can vary, the average volume can shift through time, or it can change abruptly by a variety of reasons, e.g. product or production technology obsolescence due to innovation (e.g. a 50 % cost reduction) or legislative directives (WEEE and RoHS directives). Seasonality of demand exists to some degree as well, but not as much as in consumer markets such as fashion or toy industry, where 45 percent of annual demand takes place in the last two months of the year (Johnson, 2001).

Demand fluctuation and signalling to the upstream network and how companies react to this information, was thought to depend on each partner's risk taking incentives. These incentives were believed to be in constant change in response to actualizing demand over time. As an example, risk incentives shift downstream when a supplier ends up with excess inventory after actual demand falls below forecast demand. The supplier might not accumulate stock for anything else in the future before it receives a firm order from downstream (lowering the fill rate and thus lengthening the procurement lead time). What customers should realize is that if they constantly either fall below or exceed the forecasted demand, they are actually the source of the increasing variability and growing lead times for these products, which is the very problem they would normally complain about.

The root causes of the uncertainty in demand requirements may be impossible to define – they may be composure of an infinite number of factors. On product level however, they were thought to be correlated with several things related to the customers. To put it another way, the *certainty* of demand requirements is positively correlated with the size and homogeneity of the customer base. This idea relates to the notion that several customers' forecast inaccuracies would offset the undesirable effects of each other. These ensure a steady flow of demand and reduce the excess risk of purchasing. This finding relates to buyer behaviour: where demand is steady, excess purchase risks are lower and thus supply risks are reduced.

It was not studied in this round of interviews, but continuing with the assumption that any variations in demand requirements (especially as compared to forecasted demand) would increase the potential excesses or shortages – especially in the case of an excess – the risk aversion in the supply chain increases. In that sense, production lead times in an industry should follow either increasing or decreasing trends, rather than a jigsaw trend. That idea is based on the assumption that one actualized excess at any tier level will decrease risk taking and a longer lead time on the other hand will increase inbound supply risks. Therefore a hypothesis is made that increasing or decreasing trends of uncertainty become endogenous, but to the author's knowledge there is no empirical data to prove this point.

The risks of demand uncertainty are augmented by asset specificities. If the products are customer specific, the production may require investments in specific technologies or R&D. The expected business may seem lucrative, but the risks are also high (a dynamic risk perspective). The demand requirements mix is driven by a constant change from technological innovation. Asset specificities can be avoided to some degree by postponement strategies, standardized modular design and product harmonization. According to Interview C, customer specificity can be the result of persistent -even unjustifiable- customer requests even if substitutes existed. Product substitution may be inhibited by contractual issues as well (contract level, code level, etc.).

To combat demand uncertainty, forecasting is encouraged. Forecasting is factually a risk management tool, but being inaccurate it may actually increase supply risks. Forecasting and its accuracy were thought to be some of the most challenging risks related to operations. The risk sharing between the OEM and the supply base is a factor that might increase supply risks, if the risks related to the inaccuracies are not fairly distributed, i.e. if the OEM would assume no liability but require full commitment from suppliers to forecasted demand.

Risks that were un-emphasized

Price escalation risk was considered an important aspect of supply risk in literature. In case interviews this point was downplayed (e.g. Interview B). Prices could become a source of supply risk in the case of prolonged price negotiations if no price could be agreed upon or if the viability of specific technology investments were in disagreement. The most usual concern is simply the longer delay in receiving order confirmations. If the relationship is otherwise in good condition, price negotiations should not stop production, even if the price was pending. If the product supply is under a single source, the supplier has more bargaining power and the incentive to push up the price, but this is a short-sighted strategy and does not serve the purpose of achieving mutual goals in the long term. Furthermore, if the OEM's target pricing is not met, the supplier runs the risk of the OEM starting to look for alternatives (Interview B).

3.3.4 Risks of the macro environment

The risks of the macro environment are common to all companies in the industry and have sources that are external to them – i.e. from the surrounding environment. The identified sources of risks are related to legislative, operative, business, political, bureaucratic[6], and other miscellaneous environmental factors. These types of risks are usually the most uncontrollable ones and can have a significant influence on any company's activities. Legislative changes can occur suddenly, or they can be anticipated, but the effects may tax a heavy load on all companies. Good examples are the requirement of RoHS compliance (2002/95/EC), effective since 1 July 2006, and the related WEEE directive of waste management and recycling (2002/95/EC). RoHS compliance confines the usage of six hazardous materials in the manufacture of various types of electronic and electrical equipment. In effect, this has sometimes created two separate material flows to manage – when some non-EU customers have not accepted RoHS compliant products (Interview E). Business environment relates to all economic factors that influence companies' financial stability and risk taking. For example the Great Telecoms Crash in 2000 resulted in sizable reduction of telecom equipment suppliers and the resultant global demand for certain components and materials far exceeded the total supply (Interview E). Political risks include any sort of political instability in the host country of operations or sourcing or other politics related requirements: for example, there are a variety of sales restrictions and trade bans. Some manufacturers restrict sales of their products to

[6] Bureaucracy: (4) complex rules and regulations applied rigidly (Encarta Dictionary)

customers in certain countries. More commonly, several customers do not accept manufactures from certain originating countries because of political reasons. Bureaucratic risks are abundant and they basically increase workloads, slow down processes, etc. Introducing new logistics service providers (LSPs) or new lanes to existing LSPs may increase supply risk if the booking process is not established, or the LSP underperforms. Different Incoterms have different properties, some causing increased supply risk due to lower visibility (e.g. DDU/DDP vs. EXW/FCA). Other macro-environmental risks that are difficult to place under any one specific heading include examples such as certain financial arrangements like reimburse loans. These loans have a fixed time frame for export customs clearance. Another example is customs technical requirements: for example, some Latin American countries require consolidated shipments; others sealed trucks, inhibiting LCLs (less than container load), etc. even if the actual roll-out installation of the telecom equipment would be required during a longer period of time. All of these issues can result in several parallel material flows and demand peaks that in reality could be simpler or more uniform.

3.4 Risk correlations matrix

It is useful to conceptualize risk in terms of its manifestation in supply chains. Each company has risks that are implicit to it and since companies have transactions between each other, the implicit and internal risks unavoidably affect the transactions. When another company is dependent on the transaction – e.g. the supply of goods – it is subjected to the other company's implicit risks. Each company thereafter faces risks from external sources that are related to the macro environment, and each one reacts and manages them differently. For example, a 3-tier supplier is affected by certain external risks more than its customers, but as the customer is subjected to the supplier's implicit risks through transactions, its risk position changes to some extent. The magnitude of change through these indirect effects varies case by case, but it can be concluded that network risks are greater than the sum of each company's implicit risks.

Another distinction is that the risk sources have correlations between themselves. This section uncovers some of the relationships of company-internal risk correlations and reflects these to the relationship between an OEM and its 1-tier supplier. These findings are based mainly on the case company interviews. Confined by the limits of validity, these results can be generalized to any industry since all companies engaged in value adding activities face risks, regardless if the subject matter is telecom equipment, agricultural products, or toys. In other words, the themes are general and the findings should be applicable to other industries as well. In the following text, the words 'dependent – explained,' 'independent – explaining,' and 'risk factor – risk variable – risk source' are used interchangeably.

Some risks may have direct causal relationships of varying magnitude, while others are only correlated. One independent variable might explain a certain percentage of the affinity of a dependent variable. The dependent variable thereafter might be the independent variable to another dependent variable. Based on a qualitative assessment, it seems plausible that the risk factors propagate the likelihoods of other risk factors, creating a complex and dynamic web of direct and indirect relationships. Having a high risk level for one factor possibly forges an otherwise acceptable risk for another factor unacceptable. From risk management perspective, it is beneficial to understand these dependencies. After risks are identified and the assessment is validated, understanding the dependence relationships of risk factors increases the accuracy of the company's overall risk position. Based on the qualitative research approach in this thesis, a preliminary proposition is represented in Figure 3-4. The procedure of achieving this representation and its implications are discussed in the following paragraphs. It is important to remember that the defined risk event of these risk factors *is a supply failure from a 1-tier supplier to the OEM*, and that the factors do not represent the ultimate cause of the supply failure, but the overall propensity for any potential cause to emerge (as illustrated in Figure 3-3). One such factor is the excess purchase risk, which is not a supplier nor product related risk per se, but it is dependent on the product characteristics and several supplier related issues, and it is one of the essential contributors to potential supply failures in hub inbound. Some factors are likely to have only neutral of negative correlations to the propensity of supply failures: for example, customer prioritization may in fact alleviate this risk if it is at a level above the average.

			Dependent variables									
			FACTORS THAT SHOULD BE BEST EXPLAINED									
		Strenght of effect 1 - low 3 - moderate 5 - high	Procurement lead time	Overall supply flexibility	PM / R&D / Technology	Excess purchasing risk	Customer prioritization	Financial stability (of the supplier)	Forecast accuracy	***Sum total, 123***	***Rank***	***Percentage of total sum***
Independent variables	SUPP	Level of alignment	**3**	**5**	**4**	**4**	**5**	**1**	**0**	*22*	***1***	18%
	PROD	Changes in demand requirements	**3**	**3**	**5**	**5**	**1**	**1**	**3**	*21*	***2***	17%
	SUPP	Supply base management	**3**	**5**	**5**	**1**	**1**	**3**	**0**	*18*	***3***	15%
	PROD	Technical complexity of the product	**5**	**3**	**5**	**3**	**0**	**0**	**0**	*16*	***4***	13%
	PROD	Substitutability of the product	**3**	**5**	**3**	**5**	**0**	**0**	**0**	*16*	***4***	13%
	SUPP	Financial stability (of the supplier)	**1**	**3**	**5**	**0**	**3**	**0**	**0**	*12*	***5***	10%
	SUPP	Sub-supplier risks	**5**	**3**	**0**	**1**	**0**	**3**	**0**	*12*	***5***	10%
	PROD	Product weight and volume	**5**	**1**	**0**	**0**	**0**	**0**	**0**	*6*	***6***	5%
		Sum total, 123	*28*	*28*	*27*	*19*	*10*	*8*	*3*			
		Rank	***1***	***1***	***2***	***3***	***4***	***5***	***6***			
		Percentage of total sum	23%	23%	22%	15%	8%	7%	2%			

Figure 3-4: Risk correlation matrix

The rows and columns in Figure 3-4 have been achieved through an iterative process, which is shown in Figure 3-5 and Figure 3-6 and explained in the following. In the first one of these figures, all of the risk factors related to products (somewhat modified from Table 3-2) are cross-tabulated in order to test for dependencies and the explanatory power of each. Each factor is represented both on one of the lines and on one of the columns; the independent factors on the rows and the dependent factors on the columns. Each cross-section is analyzed and the strength of the estimated effect is written in the empty space (measured as the effect of the independent factor *on* the dependent factor). The measurement does not consider whether the factor has a positive, negative or quadratic correlation with the independent variable – only the magnitude is estimated. Summing up the numbers in each row indicates the overall explanatory power of that factor, within the specified fields. Summing up the numbers in each column indicates the level of dependency of that factor. In Figure 3-5, the results of the analysis show that the most dependent risk factor is 'excess purchase risk,' which can be explained as a function of e.g. the number of supply sources, the procurement lead time, obsolescence risk, and any issue related to demand uncertainty. Purchasing in excess naturally does not increase the risk of supply failure, but the potential of the inventory eventually to end up in excess increases the buyer's risk aversion, which *does* increase supply risk. Second most important dependent factor is the 'procurement lead time,' which is best explained by the number of supply sources, supplier risks, the weight and volume of the product (case-dependently increasing transportation times), and the technical complexity of the product (increasing sub-supplier risks through e.g. materials availability). The least explicable risk factors, by this categorization, are supplier risks, changes in demand requirements, and some product characteristics like its weight, volume and value. Naturally, the causes of these ones are found somewhere else.

The factors with the highest explanatory power in Figure 3-5, or influence on other factors, are changes in demand requirements (increasing excess purchase risk, forecast accuracy and all other issues related to demand uncertainty), technical complexity of the product, substitutability of the product, and the weight and volume of the product, which is at times quite a significant contributor to the procurement lead time. As can be understood via the logic of this table, when one factor is risky, it will affect other factors that can in turn inflate the next ones, resulting in an endless spin of iterations. Why the risk levels do not inflate to infinity is because this categorization does not take into account every possible factor, and the influences are always only partial, thus having diminishing effects.

Independent variables		Strenght of effect 1 - low 3 - moderate 5 - high	No. of supply sources	Supplier risks	Procurement lead time	Quality conformance	Excess purchase risk	Demand variance	Changes in demand requirements	Substitutability of produc	Forecast accuracy	Value	Weight and volume	Obsolescence risk	Technical complexity		Rank
		Dependent variables →	Supply uncertainty					Demand uncertainty				Product characteristics					
Independent variables	Supply uncertainty	No. of supply sources			5		5									10	5
		Supplier risks			3	5	1									9	
		Procurement lead time					5							1		6	
		Quality conformance			1											1	
		Excess purchase risk														0	
	Demand uncertainty	Demand variance					5				5					10	5
		Changes in demand requirements			3		5	5		5	5				5	28	1
		Substitutability of product	5				5	3								13	3
		Forecast accuracy					5	0						5		10	5
	Product characteristics	Value (and value addition)	3		1		5									9	
		Weight and volume			5		5					1				11	4
		Obsolescence risk			1		5									6	
		Technical complexity	1		3	3				3		3		3		16	2
			9	0	22	8	46	8	0	8	10	4	0	9	5		
		Rank	4		2	5	1	5		5	3			4			

Figure 3-5: Correlations internal to product risks

The same procedure as above is carried out for supplier risk factors, as shown in Figure 3-6. These factors have been slightly modified from the original supplier risk classification in Table 3-4, Section 3.3.1. According to this assessment, the top five dependent factors of supplier risks are 'PM / R&D / technology,' customer prioritization, financial stability, overall flexibility and capacity, and the dependence on the OEM. These values are only indicative, because there is no exact way to measure the correlations – especially in the case of financial stability, which has more utility as an independent rather than dependent factor in this analysis. It was included both as a dependent and independent factor in Figure 3-4, but as can be seen – its ranking as a dependent factor fell to the last position, representing only 7 percent of total sum. As an independent factor it remained a bit higher in the ranking, representing 10 percent of total sum.

Of the dependent factors in Figure 3-6, the highest ranking category 'PM / R&D / technology,' is best explained by the characteristics related to the 1-tier supplier's supply base, the level of alignment, and financial stability. Maybe more interestingly, according to this assessment, the 1-tier supplier's customer prioritization (rank number two) may be well explained by the risk taking incentives, willingness to cooperate and financial stability. It is logical then to look at what explains the supplier's risk taking incentives. It seems that the main factor is the level of alignment, which then again depends on strategic factors in the longer term – as discussed earlier in the section of risks related to suppliers (3.3.1). Customer prioritization was found to have an alleviating effect of supply risk: if there was an increase in demand over the forecast, the supplier might be willing to sacrifice some of the capacity reserved for other customers, to increase production – or it could run overtime shifts. For that purpose, the supplier has to have flexibility in its capacity utilization rate, which was the fourth ranking dependent factor in Figure 3-6, followed by the overall capacity. The 'overall capacity' -factor was assessed assuming that it includes the supplier's own sourcing of finished parts.

The top six explaining factors of supplier risks overall were: financial stability, the level of alignment, sub-supplier risks, supply base management, the dependence on the OEM, and customer prioritization. Even though three of these are included in the top dependent factors, none of these are in disagreement (e.g. customer prioritization as a dependent variable is explained by risk taking incentives, whereas customer prioritization as an independent variable explains almost only the supplier's willingness to cooperate). The top two ranking factors have been discussed already – they are important to assess, because they explain much of the other risk factors affinity. The sub-supplier risks are a very important feature as well, as revealed by some of the case interviews. They affect supply risk by increasing the complexity of the supply base, 1-tier supplier sourcing capacity, technology development and operative capability. In direct relation to the sub-supplier risks is the capability of the 1-tier supplier to manage and control these risks. The 1-tier supplier's dependence on the OEM explains customer prioritization, willingness to cooperate and to some extent also its financial stability.

Independent variables	Strenght of effect 1 - low 3 - moderate 5 - high	Supply base: Complexity	Supply base: Management	Supply base: Sub-supplier risks	Supplier capacity: Overall capacity	Supplier capacity: Overall flexibility	Supplier capacity: Customer prioritization	Risk taking incentives: Dependence on OEM	Risk taking incentives: OEM dependence on supplier	Risk taking incentives: Level of alignment	Competences: PM / R&D / technology	Competences: Operative capability	Competences: Competence and reliance on personnel	Competences: Willingness to cooperate	Competences: Financial stability		Rank
Supply base	Complexity				3	3					5				1	12	
	Management	1		5	3	3					5	5			3	25	4
	Sub-supplier risks	5			5	5					5	3			3	26	3
Supplier capacity	Overall capacity					5	1	1								7	
	Overall flexibility			1			1	1								3	
	Customer prioritization								1		3			5		9	6
Risk taking incentives	Dependence on OEM		1			1	5				1			5	5	18	5
	OEM dependence on supplier						5									5	
	Level of alignment						5	5	5		5			5	3	28	2
Competences	PM / R&D / technology							3	5						5	13	
	Operative capability		5		1	1									1	8	
	Competence and reliance on personnel		1		1	1					3	3			3	12	
	Willingness to cooperate						5			3					1	9	
	Financial stability		3		5	5	5	5			5	1	1	1		31	1
		6	10	6	18	24	27	15	11	3	32	12	1	16	25		
	Rank				5	4	2	6			1				3		

Figure 3-6: Correlations internal to supplier risks

Finally, the risk correlations matrix shown in Figure 3-4 was created by selecting eight of the highest ranking dependent and independent factors, and comparing them in a similar matrix. It was expected that this would utilize the factors that have the best explanatory power and using them to analyze the factors that seem to have the highest dependency. The results show an interesting ranking; the highest explaining factor now seems to be the level of alignment, which is a highly strategic matter in the long term. The second factor is the level of changes in demand requirements. Obviously if customer requirements change constantly, it is very difficult to keep up with the technological novelty and mass production in order to respond to these changes. This is an issue that has been concluded in the literature as well. Third is the supplier's supply base management, which enables the company to coordinate better the material flows it sources from upstream partners (i.e. a high negative correlation with supply risk). Technical complexity increases the requirements from the upstream or the supplier's own technology, more valuable products, etc. Substitutability of the product is also one of the fundamentals of supply risk: if there are two products with 100 percent substitutability, the overall supply risk for that product is 50 percent less (assuming perfectly similar suppliers). Once again, financial stability is one of the hygiene-level explanatory factors for many risks. A financially stable company is able to absorb shocks and failures, periods of declining orders, etc. In addition, the company has the possibility to take speculative risks in order to gain profits (but whether it wishes to do so, depends on its risk taking incentives). Sub-supplier risks were discussed before and the last category, product weight and volume, was one of the higher ranking factors because it potentially increases the procurement lead time.

The factors that should be best explained within the two sub-categories of risks related to products and risks related to suppliers, are in order of rank: procurement lead time, overall supply flexibility, 'PM / R&D / technology,' excess purchasing risk, and customer prioritization. The less dependent factors after the classification method in Figure 3-4 have a lower ranking here because the factors that best explain them, were not among the top eight that were included in this classification. Furthermore, this is not a problem, because this classification did not measure the top eight *causes* of supply risk, but the top eight factors that have the highest dependency on the other risks. This correlation matrix will be useful during the assessment and prioritization phase of the risk management process. Risk assessment will become more accurate after risk correlations have been taken into account, since each risk may receive additional emphasis from other risk sources that have an effect on it.

There are certain limitations to the usefulness of the analysis. The estimated impact for each factor has been obtained by subjective and currently unverified method of assessment, which is largely based on the notes from the case interviews. In order to increase the validity, it would be necessary to develop assessment methods of each risk factor implicitly. With that added capability, it would be possible to measure these correlations more accurately. In addition, the correlations would need to be reached through a wider consensus and statistical testing for significance. Finally, the dependent variables in the risk correlations matrix might gain better explanation with some other types of independent variables, i.e. the greatest explanatory potential has not been statistically tested because the method has not been purely quantitative either. However, this analysis contributes to the general knowledge of the inherent correlative relationships of the factors that propagate supply risk. This functions as a starting point for continuing the development of the knowledge on risk correlations. A quantitative estimation of risk correlations could go as far as developing a robust mathematical formula for each dependent risk variable as a function of the least correlated independent variables. There exist several multivariate statistical techniques that seem promising in this field. They also consist of step-wise procedures to remove unneeded independent variables from the equation, based on their explanatory power and correlation.

3.5 Risk auditing process

As discussed in the literature survey, the proper management of risks, or inbound supply risks in this case, requires not only completing a one-off risk management study, but implementing a continuous follow-up procedure (see e.g. Figure 2-2: Supply network risk tool (Harland et al., 2003) on page 11). Currently, the OEM's supply risks are identified as part of a systems audit during supplier selection phase or more specifically after a trigger that initiates a separate audit process. According to Interview D, currently the triggers include e.g.:

- long enough time since previous audit,
- a technology transfer situation,
- continued quality or delivery problems,
- fast growth of the supplier,
- any other valid and specific reason or request.

To implement supply risk auditing as a continuous process at the case company, a suitable process needs to be defined. Part of the process is to identify the most relevant risk sources, agree on their assessment, conduct the analyses and agree on follow-up procedures. The focus of this study was on the first step – supply risk identification. This study should provide a useful tool and starting point for the process, since according to Interview D, the difficulty is in choosing what to audit. Currently the supplier selection phase audit process seems to be on quite a general level, because it need to suit the needs of all corporate functions. At least no specific framework for measuring operative supply risk exists, nor is such required from the suppliers yet. However, when delivery capability audits have been made, typical non-conformities that have arisen with new suppliers are how the supplier manages its supply base and how the OEM's forecast passes through the upstream supply chain. This gives rise to the importance of incorporating a thorough assessment of operative risks that endanger the continuous flow of supplies to the OEM. As financial stability was seen to influence all operative activities, it would be an issue to monitor continuously also from the point of view of operative supply risk. Indicators of financial health of suppliers can be obtained from finance and control at request.

4 Conclusions

Inbound supply risk is a phenomenon that is facing every company engaged in value adding activities as part of any supply network. In order to ensure a reliable and continuous flow of supplies from the supply base, a company has to have a risk management process in place. That process includes risk identification, classification, assessment, prioritization and management. Suggestion is to include also the assessment of risk correlations, as was discussed in Section 3.4. This study focused on the first step of the process, the identification of an extensive amount of factors that increase the overall propensity of supply failures occurring in the hub inbound of a global OEM telecom equipment supplier. Risk identification includes defining both the outcome and impact of the risk event. Risk impact was concluded to inhibit the OEM's from fulfilling end customer demand as requested. This chapter summarizes briefly all the contents of this thesis from both the literature survey and the empirical research (Section 4.1) and highlights the main findings and conclusions made (Section 4.2).

4.1 Summary

The general risk concept is broad. It consists of the risk perspective, the entity that experiences the risk, the definition of the risk event, and the outcome and impact of the event. Risk perspectives can be speculative, static, dynamic or inherent. Speculative risks can contain expectations of gains; static risks are only negative impacts on the entity; dynamic risks are varying and unpredictable conditions; inherent risks are inevitable harmful factors, constantly existent in operational phenomena.

Modern companies are aligned in supply chains and networks, where outsourcing has a big role. The increasing complexity of network structures and the higher dependency between companies increases exposures to uncertainties of a diverse range of sources and contexts. Key drivers of supply base complexity are globalization, increasing product and service complexity, and e-business (Harland et al., 2003). In that sense a certain level of complexity is necessary to respond to these demands. In the case study section, the hub operating model is introduced. By simplification, the OEM delivers fully functional base station configurations by consolidating the required products from external suppliers into regional hubs. Supply risk is defined as the failure of a 1-tier supplier timely delivering goods to the hub of the buying company.

A risk has a probability of occurrence and an impact. The probability is generally divided into objective (e.g. frequency or propensity) risk and subjective (strength of intuition) uncertainty interpretations. The impact varies in nature and significance: it can be a constant or a distributed variable. Inbound supply risk is the event of a supplier failing to deliver scheduled or requested goods in time, resulting in the inability of the buying firm to fulfill end customer demand, which further results in order backlogs, potential loss of sales and loss of customer (Zsidisin, 2003b; Zsidisin et al., 2004) and procurement expediting costs. In the hub operating model, it can also lead to an increased inventory costs. The likelier and more serious the risk is, the more it affects the entity and may need to be managed. Supply chain risks are divided to operative and disruptive risks (Tang, 2006). Operative risks, which are the topic of this thesis, are inherent uncertainties related to e.g. uncertain demand, supply and cost. Disruptive risks are natural and man-made disasters such as earthquakes, fires, strikes and economic crises. A risk event can have a parade of causes, and measuring the likelihood each one of them is not possible. Risk identification thus resorts to proxies that represent the likelihood of supply failures: e.g. the most relevant leading indicators of a supplier's delivery performance. Although risk itself has been researched in abundance (e.g. Hallikas, 2003), there is minimal research on how buying companies assess risks of inbound supply (Zsidisin et al., 2000), although there are a multitude of risks faced by networked organizations (Hallikas, 2003, 48). The hub operating model of the case company brings additional severity to the impact of a supply failure: whole deliveries can be delayed if any one of the required products on one customer purchase order is missing, thus propagating the total risk impact for the dependent items. Customer purchase orders typically contain a large number of separate items, whose inbound channels are anyway separate. Hence the requirement for balancing risk management efforts per each supplied item.

Risk management process is a method that contains all relevant steps required for managing any pre-defined risk event and outcome. The process starts with risk identification and qualitative or quantitative assessment of risk likelihoods, impacts, and durations, and then managing the risks. Zsidisin et al. (2004) have studied risk assessment methods as part of risk management processes.

Companies can assess supply risks with techniques that address quality, improve processes, and reduce likelihoods of supply disruptions. Methods range from informal to formal. Typical procedure is to estimate probabilities with qualitative scales (subjective probabilities), evaluate the likely duration, and investigate the business impact. Companies usually have either stand-alone processes or they do the assessments as part of proactive supply management, which is noted a proper risk management method by Smeltzer and Siferd (1998). As stated before, the measurement of the likelihoods can be subjective or objective, but often cannot be accurate because of the dynamic nature of risks. According to the assessment, the most relevant risks are managed based on the justification that net utility is positive – the reduction in risk exposure equals or surpasses the required investment in value. The challenge is converting risks into monetary terms. Methods for supply risk management work for a pool of causes and there are two basic approaches (Zsidisin et al., 2000): reactive buffering strategy and proactive process improvement. As risks of all supply chain business partners are interrelated, risk management and follow-up procedures need to be continuous and collaborative, outlined in the network risk strategy. This thesis elaborates and increases the number of currently discovered sources of inbound supply risk. A proper identification of risk sources increases the validity of the risk management process. According to literature and case interviews, the supply risk propagating factors seem to be related to suppliers, products and the macro environment.

Risks related to suppliers include e.g. capacity and flexibility, financial stability, power structures, person risks, the complexity of the supply base, and the risks faced by 1-tier suppliers. A supplier's capacity enables coping with the volume of demand. Flexibility is required for responding to demand variance. Financial stability affects supply capability in many ways, especially if a supplier has liquidity problems. A good financial stability is the hygiene-level requirement for operability: it enables the company to absorb slight set-backs and ensures the liquidity to invest into development. Power structures and risk sharing in supply chains depend on asymmetries in the relationships and bargaining power. These can result in supply risks if the depth of relationship is low and opportunistic behaviour occurs. Asymmetries, unfair risk sharing, and financial dependence on the business partner are risky, if either one cannot withstand the variances in demand. These risks are interrelated and can augment each other. Person risks are risks of specialized expertise concentrating on few key individuals and the risk of losing intellectual capital. Certain level of complexity of the supply base is required to respond to increasing product and service competence, but over-complexity results in supply risk (Choi and Krause, 2006).

The risks faced by 1-tier suppliers affect the risks that the OEM experiences when dealing with it. These include uncertainties in the relationship status and direction, selection of technologies and investments in them, compatibility of IT-systems, and issues of co-operation. Most risks faced by 1-tier suppliers affect the OEM at least indirectly. Investments in technologies increase operative risks on a more strategic level: if the selected technology does not suit the end customer needs, in most cases the supplier is left with the liability and profit loss. IT-system incompatibility increases supply risk through distortion of information; inaccuracies and delays resulting in the bull-whip effect (Lee et al., 1997).

When the discussion is taken onto item level, more details of the operative risks unfold. Since the risk event was defined as the supply failure of an individual product in hub inbound, the proxy for the overall risk probability should be measured eventually in terms of risks related to individual products. Item level risks are then divided to uncertainties in demand, which increase supply risks; and uncertainties in supply, which depend on supplier and sub-supplier risks (affected by risks faced by the suppliers itself). Uncertainties in product supply also vary within the same supplier depending on the product's characteristics like complexity or procurement lead time. This framework was proposed in Figure 3-3 on page 44. All companies also face the macro-environment risks. These are external to all of them and each one reacts and manages these risks differently.

Product level supply uncertainty (in addition to supplier risk) was found to depend on the number of supply sources; multiple-, dual-, or single sourcing, procurement lead time, quality conformance and OEM buyer risk aversion[7]. The number of sources is directly correlated with supply risk: one source may enable better control, but dual or multiple sources provide back-up when one supplier fails. The usability of more than one source depends on the product's substitutability, which may be very low especially in the short term if products are substitutes only in terms of functionality. A product's procurement lead time depends on the fill rate or production lead time, topped with

[7] This risk source is classified here for the sake of convenience and simplicity, although it is not a risk internal to product supply, but rather the OEM.

transportation lead time. The longer and more variable the procurement lead time, the higher the supply risk propagated by demand uncertainty. These are the fundamental causes of item level supply risk. Non-conforming quality can also cause delays during product receipt. In the worst case of non-conforming quality, products are sent back to the supplier.

Risks of the macro-environment include legislative, operative, business, political, bureaucratic, and other miscellaneous factors. These can have various effects on operative inbound supply. Examples of legislative hinders given in the text were RoHS compliance that restricts the use of certain toxic raw materials, resulting in separate material flows, and WEEE waste management legislation. Business factors like economic swings or industry specific catastrophes affect all companies. The Great Telecoms Crash in 2000 resulted in a drastic reduction in the supply network and compromised the global availability of many materials. Political risks restrict companies' activities in the host countries. In one example, the forced shutting down of a supplier's factories by the host government resulted in zero supply for certain critical materials. Politics can also restrict free trade, or deny products of certain origin countries or end customer countries. Bureaucratic reasons slow down processes and sometimes result in unavoidable suboptimal actions.

This study also investigated the inherent correlations between the sources of supply risks. This method of assessing risk correlations seem a highly useful in the process of assessing the overall supply risk position of a company, because it seems that the risk sources have the tendency to propagate the likelihoods of each other. These effects were proposed as a risk correlations matrix in Figure 3-4, by utilizing the classifications of product and supplier risks as the basis. According to this qualitative assessment, it was found that the top five most explicable (dependent) factors are 1) procurement lead time, 2) overall supply flexibility, 3) product management / R&D / technology competence, 4) excess purchase risk, and 5) customer prioritization. If individual risk sources are out of control, they can have rippling effects towards other operative risks.

In the assessment of product and supplier risk correlations separately, it was found that the top three dependent factors of product risks are 1) excess purchase risk, 2) procurement lead time, and 3) forecast accuracy – and the top three factors that explain most of the correlations are 1) changes in demand requirements, 2) technical complexity (of the product), and 3) substitutability of the product. This highlights the assumption that demand uncertainties have significant effects on supply risks, especially when they are compounded with supply uncertainties. In the assessment of the supplier risks, the top three dependent factors are 1) product management / R&D / technology competence, 2) customer prioritization, and 3) financial stability. The top three independent factors are 1) financial stability, 2) level of alignment, and 3) sub-supplier risks. This underlines the differences between these two classification categories. Since some of the supply risk sources have the greatest total impact on the other sources, it can be concluded that these may be the most beneficial sources to improve. But as the study inherently suggests, the independent factors are more independent, i.e. less dependent, than the factors which they explain. For that reason it may be difficult to affect these factors by management.

4.2 Main findings

The topic of this thesis was to explore supply risk characteristics of modern company networks from the perspective of a global OEM telecom supplier. The research problem was: "what are the most relevant causes of operational inbound supply risk from an external supply base that compromise the delivery capability of an OEM supplier, and how can the OEM identify and classify these risk causes on a product level aggregation?" The goals of this research were to

1. define and increase the understanding of supply risks and impacts in networks and propose a framework for product level risk assessment,
2. identify and classify the most relevant sources of inbound supply risks, specifically in the hub operating model,
3. discuss the correlations and dependencies of the risk sources,
4. outline the complete risk management process.

The answer to the research problem was sought after by investigating the concept of risk broadly and then sharpening it down to the context of modern demand-supply networks and their increasing risk exposures. The characteristics of outsourcing relationships and drivers of globalization were seen to increase the requirements towards OEM suppliers. Customer demands and demand requirements are in constant change, reflected in the increasing complexity of product and service technology. The complete process of risk management was discussed in the context of supply risks in global supply networks. Characteristics of globalization and the types of exposure risks were reviewed.

The question of how the OEM can identify and classify risk causes on a product level aggregation was illustrated and outlined in a framework in Chapter 3. Based on the lessons learned from the case interviews, it was concluded that the proper way of measuring the overall propensity of supply failures in hub inbound requires product level aggregation of the considered issues. That realization enabled conceptualizing the framework in Figure 3-3 on page 44. It follows that product level supply risks depend on factors that are directly caused by the product's properties or can be indirectly assigned to the product; they depend on risks related to the supplier of the product; they depend on risks faced by the supplier of the product itself; and they depend on risks of the macro-environment. It was discovered that starting from product-level risks, the next aggregation of risk sources is on company-level. In addition, every company involved in the value adding chain of the end product, is in transactional relationship with one or more of the other companies. These transactions are subjected to the implicit risks faced by each company, and thus the downstream partners -or the buying companies- are always subjected to the implicit risks of the upstream partners through these transactions. Furthermore, this study introduced an important addition to the assessment part of the risk management process: the inherent correlations of risk propagating factors. It became obvious through the interviews and the literature survey that there are such sources of supply risks that -besides propagating the likelihood of any ultimate cause of a supply failure- they also propagate the likelihood of some of the other risk factors, but through varying levels of impact, duration, and types of correlative relationships (positive, negative, quadratic, direct, indirect, etc.). The correlations internal to product level risks and supplier level risks were tested separately. The highest ranking dependent and independent factors were separated and compared together, obtaining the risk correlations matrix as shown in Figure 3-4 on page 66.

In approaching the main contribution of this research and answering the research problem, goal number four became covered in the process. The complete risk management process was walked through in order to set the basis for the extensive identification of supply risks. Several supply risk propagating factors were found from the literature review. However, the definitions of supply risk have always been somewhat vague. This study manages to improve the exactness of the risk event. A supply risk as it is classically illustrated in literature, is not the cause of a supply failure, but is any of the most relevant factors that make part of a supplier's delivery performance. Thus all *operative* supply risk factors that have been discussed in literature are in fact measurement proxies of different aspects of the supplier's delivery performance. It was concluded in this study, that it is impossible and inutile to identify and assess the probability of all causes that can result in supply failures, but that the process of increasing measurement targets should be based on the marginal utility of doing so: the reduction in risk exposure should equal to or exceed in value the required investment to manage that cause. Because the approach is two-fold: proactive process improvement or reactive buffer strategy, it makes sense to pre-emptively tackle supply risk issues that at the same time reduce operative instability and reap the highest possible benefits from process improvement.

The main findings of operative supply risk, starting from product level aggregation are related to supply and demand uncertainties, and product characteristics. Supply uncertainties as classified in Table n-n, consist of the number of supply sources, the implicit risks of the product's supplier, the procurement lead time, quality conformance, and lastly of the excess purchase risk which is reflected as the buyer's risk aversion. The last category is not a supply risk per se, but it is practical to classify under the heading of supply uncertainties as it propagates the likelihood of such. In the future, it is worth considering adding a completely new category: supply risks propagated internally by the buying company. One of the more innovative solutions of this thesis is to include the procurement lead time in this category. It enables to focus on the holistic view on the matter – it functions as the main binding point between supply and demand uncertainties. Many of the supply risks would not cause supply failures unless it was the changes in demand during a replenishment lead time. Demand changes, dependent on various sources itself, are the source of high levels of supply risks and longer term failures like the investment in a faulty or soon-to-be obsolete technology. A study of correlations between these aspects was an interesting contribution of this thesis. In Section 3.4, a preliminary proposition of risk correlations was put forward as a risk correlations matrix (Figure 3-4). It shows how some of the risk sources depend on other risk sources. The estimates indicate strong implications between the risk sources, but the results will be more evident after the identified risk sources are developed further and also solicit exact definitions to risk assessment – be it arbitrary quantification or objective measurement where applicable.

Obviously, the category of demand risks has been widely acknowledges in literature, in terms of e.g. demand variability and the bull-whip effect. This thesis incorporates purchase risk in conjunction to demand changes. Demand changes are divided into two distinct sub-categories: changes in demand requirements mix or properties and changes in demand distribution. Conceptually, in this study the category of demand distribution includes the current and potential change of the volume, step changes in the volume, complete and abrupt stop of the volume, and seasonality of the volume, in addition to the variability in one time unit. This demand uncertainty, as stated above, is not only linked to supply uncertainty, but also to the purchase risk as a result of the demand characteristics, which depend on the customer base: the customer base size, number of customers, and heterogeneity or variance. An highly important aspect of supply risk (as any risk event is the multiple of its probability and impact) is a result of the issues within the customer base: having only a few customers for a product is associated with high purchase risk (low inventory turnover) and low impact risk (only few customer suffering from the delivery delays), and having many customers for a product is associated with low purchase risk (high inventory turnover) and high impact risk (many customers suffering from the delivery delay). Thus the result of having low purchase risk is no bliss since it is evidently balanced off by the resulting impact risk. Incorporating the indirect impacts, the risk level is even higher than in the case of high purchase risk. The rule-of-thumb conclusion that can be made is that a product with several customers and high-rolling demand should never run out of supply.

Product characteristics can increase the probability of supply failures. Much of the literature seems to study supply risks on a more theoretical level and thus ignore product characteristics such as the product's weight and volume, which can be the main determinants of transportation lead time. Naturally, the main determinant of transportation lead time is the chosen sourcing location and where in the world the demand takes place. In the hub operating model, this equation is narrowed down: the demand always takes place in the hub, since that is used as the consolidation point for all deliveries.

Similarly as in literature (e.g. Hallikas, 2003), also risks of 1-tier suppliers were considered. Unsurprisingly, they were found to have some similar properties as the risks faced by the OEM. Macro-environment risks naturally affect all the companies in the same economy -and more specifically- in the same industry. Also demand risks are similarly challenging to all parties, with varying nuances at each tier level. The 1-tier suppliers are concerned with inconsistent demand both downstream and upstream, which tend to amplify risks of both shortages and excesses. The position of the 1-tier supplier is turbulent; it has to take greater responsibilities, greater risks and manage a wide supply base in order to contribute to the success of the OEM and the whole supply chain. The supply base risks that were found important were related to the global availability of materials and labour skills: e.g. components and raw materials like lead and copper, and competent people in regions where the production is taking place. One of the greatest concerns was the uncertainty of technology investments – the opportunity costs and risks of technology failures.

The third goal of the study was to discuss the correlations and dependencies of the risk sources. This goal was set because the assumption was that the risks may have impacts on each other, one propagating the likelihood of the other. This method of assessing risk correlations seem a highly useful in the process of assessing the overall supply risk position of a company. Eventually that would require a final validation of the constructs' measurement. According to this assessment, a risk correlations matrix was proposed in Figure 3-4, by utilizing the classifications of product and supplier risks as the basis. This analysis gave rise to several very interesting findings. The top five most explicable (dependent) factors are 1) procurement lead time, 2) overall supply flexibility, 3) product management / R&D / technology competence, 4) excess purchase risk, and 5) customer prioritization. What this means practically, is that it is likely that these risk sources can be highly affected by some of the other risk sources, which is an important managerial implication – if individual risk sources get out of control, they can have rippling effects through other operative risks. According to that logic, the overall supply risk would be an exponential function of its independent factors.

The assessment of product and supplier risk correlations separately reveals interesting findings: within this categorization the top three dependent factors of product risks are 1) excess purchase risk, 2) procurement lead time, and 3) forecast accuracy, and the top three factors that explain most of the correlations are 1) changes in demand requirements, 2) technical complexity (of the product), and 3) substitutability of the product. This reveals the fact that demand uncertainties have significant effects on supply risks. In fact, demand uncertainties have the highest effects when they are compounded with supply uncertainties. Turning to supplier risks, the top three dependent factors are 1) product management / R&D / technology competence, 2) customer prioritization, and 3) financial stability. The top three explanatory factors are 1) financial stability, 2) level of alignment, and 3) sub-supplier risks. These reveal the differences between these two classification categories. Since some of the supply risk sources have the greatest total impact on the other sources, it can be concluded that these may be the most beneficial sources to improve. But as the study inherently suggests, the independent factors are more independent than the factors that they explain and it may be difficult to affect these factors.

To conclude, this thesis has succeeded in revealing and analyzing some of the most fundamental causes of operative supply risks, and taking the analysis down to the level of individual purchased products. The exact definition of supply risk was the prerequisite for the study and proper identification of the risk sources. In some cases in literature, it seems, that supply risk is defined too vaguely; they fail to mention that the identified risks do not ultimately cause the supply failures, but propagate the general likelihood, which requires the inclusion of risk proxies. That view was considered in the proposal for the framework of product level risk assessment in Figure 3-3. The risks of an OEM supplier was the main focus, emphatically in the hub inbound of an OEM telecom supplier. This study also contributed to the study of supply risk by discussing the properties of product consolidation through a consolidation point, i.e. the regional hub. It was found that the impact of a hub shortage is much greater than that of an individually demanded item. Conceptually, that makes it imperative to spread risk management resources equally to the purchased products: there is no use for a high capacity supplier of e.g. base station cabinets, if these products cannot be delivered due to the lack of a cheap missing mechanical part from another supplier.

This study answered to the last goal of introducing the complete risk management process. It was not necessary, nor possible to go through all the steps in detail, due to the limitations of the scope of this study. It was noted that in order to manage supply risks, they need to be identified, assessed, prioritized, and finally managed. This process cannot be a one-off rehearsal, but needs to be integrated into the corporation as a holistic and continuous process, which maintains the risks of the existing supplier base at an acceptable minimum level and caters for the needs of the supplier selection phase. This study was focused on the existing relationships only, and the remaining steps of the process are discussed in the next section – the suggestions for future research.

4.3 Future research

This study provided the basis for the supply risk management process; the risk identification and classification. Future research is suggested towards the following steps in process: the assessment and prioritization of the identified risk factors, quantifying the risk correlations, and studying risk management methods. The assessment methods require much attention and statistical testing, because the impact assessment of each risk source can have different proxies in different contexts. Thus they need to be on a general level to suit most of the situations. Assessing prioritization requires the ability to gauge risk impacts more accurately, which is also a very interesting but challenging and context-dependent research topic. Finally, the area that was left uncovered in this study was disruptive risks, which require the assessment of unforeseeable catastrophes and natural disasters that affect the activities of the company, for which there is usually no leading indicators. They should be managed in the reactive phase, i.e. by creating contingency plans and back-up sources of supply. That area is suggested for the case company to undertake under a holistic risk management program. From theoretical point of view, the further development of quantitative risk assessment through e.g. multivariate modelling seems necessary in the modern corporate environment.

Sources

Choi, Y.T, Krause, D.R. (2006) "The supply base and its complexity: Implications for transaction costs, risks, responsiveness, and innovation", *Journal of Operations Management*, Vol. 24, No. 5, pp. 637.

Eisenhardt, K. (1989) "Building Theories from Case Study Research", *the Academy of Management Review*, Vol. 14, No. 4, pp. 532.

Engblom, J. (2003) *Liikeriskit – luonne, lajit ja riskikentän mallintaminen*, Publications of the Turku School of Economics and Business Administration, Turku, pp. 156. (In Finnish)

Evans, J.R. and Lindsay, W.M., (2005) *The Management and Control of Quality*, 6e, Thomson South-Western, Singapore, pp. 760.

Grose, V.L., (1987) *Managing risk. Systematic Loss Prevention for Executives*, Prentice Hall: Englewood Cliffs, New Jersey.

Hallikas, J., Virolainen, V-M., Pulkkinen, U., Tuominen, M. (2002) *Managing Risk in Purchasing Strategy Selection*, Proceedings of the 11th International Annual IPSERA Conference, University of Twente, March 25-27, Enschede, the Netherlands.

Hallikas, J., Virolainen, V-M., Tuominen, M. (2002b) "Risk Analysis and Assessment in Network Environments – A Dyadic Case Study", *International Journal of Production Economics*, Vol. 78, No. 1, pp. 45-55.

Hallikas, J. (2003) *Managing risk in supplier networks: case studies in inter-firm collaboration*, Digipaino 2003, Lappeenranta Technical University, dissertation, 145 p.

Harland, C., Brenchley, R., Walker, H. (2003) "Risk in supply networks", *Journal of Purchasing and Supply Management*, Vol. 9. No. 2, pp. 51-62.

Hau, L. (2004) "The Triple-A Supply Chain", *Harvard Business Review*, Vol. 82, No. 10, pp. 102.

Herz, D. and Thomas, H. (1983) *Risk Analysis and its Applications*, John Wiley & Sons.

Johnson, M.E. (2001) "Learning from toys: Lessons in managing supply chain risk from the toy industry", *California Management Review*, Vol. 43, No. 3, pp. 106-124.

Kraljic, P. (1983) "Purchasing must become supply management", *Harvard Business Review*, Vol. 61, No. 5, pp. 109-117.

Kull, T. and Closs, D. (2008) "The risk of second-tier supplier failures in serial supply chains: Implications for order policies and distributor autonomy", *European Journal of Operational Research*, Vol. 186, No. 3, pp. 1158-1174.

Lee, H.L., Padmanadhan, V., Whang, S. (1997) "The bullwhip effect in supply chains", *Sloan Management Review*, Vol. 38, No. 3, pp. 93-102.

Leenders, M.R., et al. (2002) *Purchasing and Supply Management*, 12th ed., McGraw-Hill, Boston, MA, pp. 743.

Lindroth, R. and Norrman, A. (2001) *Supply Chain Risks and Risk Sharing Instruments – An Illustration from the Telecommunication Industry*, Proceedings of the Logistics Research Network 6th Annual Conference, Heriot-Watt University, September 14-14, pp. 297-307.

Norrman, A. and Jansson, U. (2004) "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident", *International Journal of Physical Distribution and Logistics Management*, Vol. 34, No. 5, pp. 434-456.

Prahalad, C.K. and Hamel, G. (1990) "The Core Competence of the Corporation", *Harvard Business Review*, Vol. 68, No. 3, pp. 79-91.

Silver, E.A., Pyke, D.F., Peterson, R. (1998) *Inventory Management and Production Planning and Scheduling*, John Wiley & Sons, USA, 754 p.

Smeltzer, L.R. and Siferd, S.P. (1998) "Proactive Supply Management: The Management of Risk", *International Journal of Purchasing and Materials Management*, Vol. 34, No. 1, pp. 38-45.

Steele, P. and Court, B. (1996) *Profitable Purchasing Strategies: A Manager's Guide for Improving Organizational Competitiveness through the Skills of Purchasing*, McGraw-Hill, London.

Tang, C. (2006) "Perspectives in supply chain risk management", *International Journal of Production Economics*, Vol. 103, No. 2, pp. 451-488.

Treleven, M. and Schweikhart, S.B. (1988) "A Risk/Benefit Analysis of Sourcing Strategies: Single vs. Multiple Sourcing", *Journal of Operations Management*, Vol. 7, No. 4, pp. 93-114.

Wu, T., Blackhurst, J., Chidambaram, V. (2006) "A model for inbound supply risk analysis", *Computers in Industry*, Vol. 57, No. 4, pp. 350-365.

Yates, J.F. and Stone, E.R. (1992) *Risk Appraisal*, in Yates, J.F. (Ed.), Risk-Taking Behavior, John Wiley & Sons, New York, NY

Zsidisin, A.G., Panelli, A., Upton, R. (2000) "Purchasing organization involvement in risk assessments, contingency plans, and risk management: an exploratory study", *Supply Chain Management*, Vol. 5, No. 4, pp. 187.

Zsidisin, A.G. (2002) Defining supply risk: a grounded theory approach, in: Proceedings from the Decision Sciences Institute Annual Meeting, San Diego, CD.

Zsidisin, A.G. (2003a) "Managerial Perceptions of Supply Risk", *the Journal of Supply Chain Management*, Vol. 39, No. 1, pp. 14-26.

Zsidisin, A.G. (2003b) "A grounded definition of supply risk", *Journal of Purchasing and Supply Management*, Vol. 9, No. 5-6, pp. 217-224.

Zsidisin, A.G., Ellram, L., Carter, R., Cavinato, J. (2004) "An analysis of supply risk assessment techniques", *International Journal of Physical Distribution and Logistics Management*, Vol. 34, No. 5, pp. 397.

Interviews

Interview A, OEM, Manager, Materials/Inventory Management, 21.02.2008
Interview B, OEM, Buyer, 23.4.2008
Interview C, OEM, Purchasing Manager, 5.5.2008
Interview D, OEM, Sourcing Manager, 16.5.2008
Interview E, 1-tier supplier, Global Account Manager, 23.5.2008
Interview F, OEM, Senior Specialist (Concepts), 4.6.2008

Appendix 1: Semi-structured interview questions for 1-tier supplier risks

What are the risks related to the supply base, in terms of
- Sourcing? Capability? Visibility? Sourcing composition (material + labour)?
- Excess risk?

What affects your risk taking incentives as a supplier?
- What increases, what reduces?
- What do they consist of?

What determines supply chain risk sharing? Do you find common risk sharing between 1-tier suppliers and OEMs as
- fair, unfair?
- What are the known impacts?
- Who bears the most risk?

What determines the demand risks from customers (OEMs)?
- How do demand variations affect operations?
- What are the effects of inaccurate forecasts?

How are supply chain power structures defined?
- What determines the level of dependence on the OEM?

How does financial stability affect operations?

What sort of internal risks can be recognized?
- Capacity, flexibility?

What are the main aspects of technological risk?
- Production equipment?
- Products?

How would you determine production lead time variance?
- Characteristics (value, weight, volume)?
- Quality risks?

Which are the most important functional competencies?
- How do you manage person risks?